Analyzer Reliability

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International Forum Process Analytical Chemistry January 12-15, 2004
Marriott Crystal Gateway
Arlington, Virginia

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ABSTRACT
Fundamentals of analyzer reliability issues are discussed using failure criteria required for documenting both actual failure data and censored data. An existing data set of end user supplied information is examined using Weibull analysis which is the tool of choice for most reliability studies. Recommendations are provided for obtaining better data to enhance future Weibull analysis of analyzer data.

KEYWORDS
Analyzer reliability, censored data, suspended data, failure criteria, failure data, failure modes, reliability data, reliability models, Weibull analysis.

INTRODUCTION
Reliability is the probability that a device, system, or process will perform its prescribed duty without failure for a given time when operated correctly in a specified environment.

Analyzers are small systems composed of components or devices. Each of the analyzer components must function without failure (since most of the components are functionally in series) so that the production process can operate without failure. Reliability of an analyzer always terminates in a failure. In the strategy of a production operation:

- The production process is the king and must be preserved while pawns fail.
- The analyzer is a pawn. If properly configured, analyzer failure will not kill the process.

The key is to preserve successful and reliable operation of the process while accepting small failures. If properly configured, analyzers are important but expendable items. However, if the analyzer is improperly configured into the system, loss of the analyzer can kill the kingly process though a fatal Achilles heel.

Failure of the analyzer system must be carefully defined. Nonconformities, called failures, are easy topics for conversation but often lack clear failure definitions. Most analyzers are developed, assembled, and tested in a laboratory environment using well trained operators/assemblers who "nurse" the analyzer for high performance levels. A firm criterion for instrument failure at the manufacturer's plant must involve subjecting the instrument to variable input as will be experienced in the production environment and measuring the deviations from the input to search for failure of the instrument to perform its assigned mission <u>without touching the device</u>. At a practical level, if the instrument requires intervention such as "nursing", then a failure has occurred.

By necessity, analyzers are used in a less than desirable environment (than subjected to in the laboratory or assembly area) which contributes to more frequent operational failures than occurs in the birth place of the analyzer. Likewise, analyzer(s) failure occurs if output readings between multiple instruments (or a calibration standard) vary by more than a specified amount. The inappropriate spread in variance between multiple instruments (or a standard) must be defined in operational output values, (not in % as this results in confusion for operators), and must be written down for firm criteria of failure. Failure criteria cannot be written on a rubber ruler which can be stretched and bent to meet the convenience of the moment.

Analyzer life data for reliability analysis is usually highly deficient. Therefore few sound and substantial studies of analyzers, based on hard data, are available for analysis. This deficiency occurs because a firm failure criteria is not defined, age-to-failure is not acquired, different failure modes are not clearly enumerated, and censored/suspended ages are not recorded to separate failure events from age-to-failure.

What reliability failure data should be gathered for a meaningful analysis?

- First-define a failure.
- Second-acquire data motivating the failure, and
- Third-record the exposure "time"

Abernethy (2002) defines a clear set of three requirements for failure:

- the time origin must be unambiguous [i.e., where is time = 0]
- a scale for measuring passage of time must be set [hours, cycles, etc.]
- the meaning of failure must be entirely clear [written definition required]

The time scale can be hours in service, cycles, shelf time, and so forth.

The age of time to failure for each failure mode must be separated from failures due to events. Events resulting in failure are analyzed as suspended or censored ages.

Likewise aging failures with different modes of failure also results in suspensions. The data must be carefully recorded so a meaningful reliability analysis can be performed. Unfortunately most people recording data for analyzers have never seen the results of a reliability analysis, they do not know what data is needed, and they have not seen how the data should be dissected to produce meaningful results.

The simplest but crudest data analysis is conducted at the arithmetic level using mean times between failures (MTBF) for repairable components or mean times to failure (MTTF) for non-repairable components. Sometimes compromises in the data require treating all of the failures as repairable simply to drive numeric results because repairable events and non-repairable events are not carefully categorized, thus small numeric errors are acceptable simply to have some facts for giving a voice to the data.

A smarter and wiser analysis uses carefully recorded data, by failure mode, for each component using Weibull analysis as described in the reference by Abernethy. Weibull analysis is the tool of choice for most reliability engineers because a single set of statistics allows components to fail by infant mortality, chance failure, or by wear-out failure modes by way of user-friendly reliability software, Fulton (2003). Weibull analysis has a major advantage as carefully recorded data, by failure mode, can tell you how the item failed (as opposed to using opinions to define how the component failed). Unfortunately many people express the opinion that components “wear out” when in fact, Weibull analysis may give evidence of a different failure mode, which in turn suggest a different action plan for making corrections.

The follow quotation addresses analyzer unreliability: “The general consensus seems to be that an experienced technician should handle from 10 to 15 analyzers….”, Clevett (1986). You can argue that any book about production process analyzers is immediately out of date upon publication because of the numerous changes in technology and procedures. Thus Clevett’s statement may not fit your situation. However, you will always require more analyzer support than your financial systems allow in your budget. Analyzer support is driven by unreliability of both the instrument and analyzer systems as they require considerable “nursing” for satisfactory operation in a production plant. The number of analyzer failures and repair times can be calculated from reliability data.

Today, in general, we “grade hard” about any type of failure (corrective maintenance as well as preventative or predictive maintenance) as we are confined to a limited workforce, and a general intolerance to disruptions for any reason. For example, today, we will not tolerate the “fiddling” required for a 1960’s television receiver with its many problems and short life. Today we expect our television receivers to be failure free (and adjustment free) for a period of 7 to 10 years. The change in TV failures has resulted in the demise of a trade called television repairman to a point it is a boutique business rather than a major occupation. Today, television receivers have reduced failures and longer life by use of new technology, solid state electronics, self correcting diagnosis, feedback systems, and highly redundant systems driven by a consumer who has zero tolerance for failures of any type.

Financial pressure by analyzer end-users is pressing for a failure free environment. End-users need to provide objective evidence to the manufactures in a common dialog that is understandable to both manufactures and end-users. End-users and manufactures need a common dialog based on reliability data so the dialog is fact based rather than emotion based. The dialog also requires a clear definition of failure. Be careful with engineering definitions of failure [they tend to be self-justifying with allowance for failures] To get the definition of a failure correct, define a failure from the perspective of the investor which usually demands low cost, failure free operation for a specified interval of time so as to avoid expenditures. Also end-users need to tell analyzer manufactures their requirements in simple, declarative sentences such as: “The analyzer must demonstrate an absence of failures during a 5 year mission for a reliability of 90% with an availability of 99.99% without human intervention in a production plant environment.”

In simplest of terms, a failure is: Loss of a function when you wanted the function. A more detailed definition of failure is: Failure is an event which renders equipment and processes as non-useful for the intended or specified purpose during a designated time interval. Failures include:

- Stoppage due to malfunction,
- Cessation of component function,
- Cessation of meeting predetermined quality, quantity, or cost expectations,
- An unexpected occurrence that interrupts routine operation of a system,
- In some cases, any human intervention required for any reason including cleaning, adjustments, or calibration.

Analyzer failure codes need to be established and age-to-failure data acquired to measure reliability results so that the common dialog between manufactures and end-users can occur regarding the facts rather than having a screaming match.

Another misconception between suppliers and end-users often exist over the use of terms such as availability and reliability O’Connor (2003). Availability and reliability terms are different. If you don’t get the language correct, you’ll never work on the correct problems. Availability measures the percent of time the system is alive, well, and capable of performing the assigned task. Availability for most industries has a denominator which sums to 8760 hours/year:

$$Availability = \frac{Uptime}{Total\_Time} = \frac{Uptime}{(Uptime + Downtime + PM\_Lost\_Time)}$$

Reliability measures the probability for a failure free interval. Reliability can also be an attribute measurement for a given time interval:

$$\text{Re}\,liability = \frac{Successes}{Attempts} = \frac{Successes}{(Successes + Failures)}$$

Reliability can also be a function of time (described here simply as an exponential distribution which is appropriate for a system but may not be appropriate for a component):

$$\text{Re}\,liability = e^{-\lambda t} = e^{-t/\Theta} = e^{-N},$$

λ = failure rate or Θ = MTBF or MTTF where $\lambda = 1/\Theta$,
t = mission time, and
N = number of failures over the mission time of t

Availability and reliability are both expressed in % values but they mean different things. Availability tells how you use time. Reliability tells about the probability for no failures over a given time span.

For example, if your automobile has an availability of 98% for a one year interval, we can easily see that the uptime =0.98*8760 hrs = 8584.8 hrs and the downtime = (1-0.98)*8760 hrs=175.2 hrs. If the downtime occurred from one failure then the demonstrated reliability = e^{-1} = 36.8% which says we have a 36.8% chance of operating one year without a failure. However, if during the same number of downtime hours, you experienced three failures, then your automobile would demonstrate a miserable reliability = e^{-3} = 4.99% = probability of operating one year without a failure or said another way you have a 100-4.99% = 95.01% chance for failure, during the one year mission, which is a statement of unreliability defining the probability of failure.

Availability tells about uptime and downtime whereas reliability tells the probability of operating the mission time without a failure. Often we speak correctly about availability and the uptime or downtime, but we fail to communicate about reliability which is driven by the number of expected failures during an interval.

Reliability, as an attribute, relates the probability for success. Consider the USA space shuttle failures through the time period of February 2, 2003 with 113 success out of 115 attempts. The space shuttle has a demonstrated reliability = 113/115 = 98.26% with an unreliability = 100-98.26% = 1.74% = probability of failure for successful round trips. Reliability always terminates in a failure.

Perfect reliability only exists in your fantasy world! In the real world, high reliability is never 1.0 but always quantified with a string of "point 9s" (this requires use of more significant digits than learned at the university).

Reliability issues and programs have some similarities with safety programs. Safety programs today are dedicated to zero accidents (failures) as addressed in our safety policies. Safety issues involve human learning and corrective action to prevent accidents called failures. Safety involves a mixture of altruism and money. In a similar fashion, reliability issues plan for zero failures, where reliability issues involve entropy deterioration often caused by aging effects with substantial influence by humans on reliability of the system. Reliability involves money and alternatives for how to accomplish the task for the lowest long term cost of ownership. Overall, safety and reliability programs are dedicated toward an absence of failures, and how humans interface with the system has direct impacts on reliability. For example ASME (2002): For 10 years, from 1992-2001, 127 people died from boiler and pressure vessel accidents and 720 people were injured. In the 23,338 accident reports, 83% were a direct result of human oversight or lack of knowledge. The same reasons were listed for 69% of the injuries and 60% of recorded deaths. In short, how humans perceive the system is vitally important to sustaining inherent reliability—it applies to ASME Code pressure vessels just as it applies to analyzers.

People influences on reliability occur from both the tactical viewpoint and the strategic viewpoint with two different technology drives. Maintenance engineers have the short range tactical viewpoint of quickly clearing failures and restoring equipment to operable conditions. Reliability engineers have a longer range strategic viewpoint of forecasting and avoiding failures. Both groups need to understand each others position and both need to also understand that their performance standards are significantly influenced by how humans interact with the equipment and how humans perceive both failures and the lack of failures as humans react to the system. Don't forget your humans when considering the reliability of analyzers: People can help/hurt the reliability results.

The usual reliability question arises: Why work on reliability issues? The answer is simple: It's all about money and the tradeoffs of how/when the money is spent. So in most cases, solving a reliability problem is also solving a money problem. Reliability details tell you how often the system fails, and maintainability issues tell you how long it takes to make repairs. These two issues drive the expenditure of time, effort, and spare parts which gets you to time and money. You may think of the technical issues for analyzers, but I assure you the real issue is all about time, money, and alternatives!

ANALYZER RELIABILITY MODELS

Nichols (1988) shows many different analyzers in a format that is adaptable to a reliability model when appropriate reliability data is employed. Most analyzer reliability models show long series strings of components. Long series strings are fraught with failure problems because failure of any item in the series model causes failure of the analyzer system. Figure 1 shows a reliability model of a typical gas chromatograph. This model and its failure rates, represents no specific instrument, but in general, it represents all gas chromatographs.

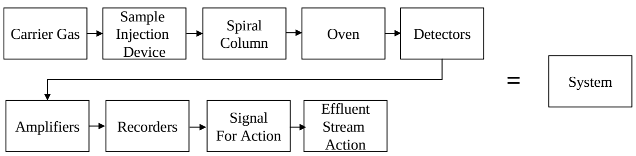


Figure 1: Gas Chromatograph Reliability Model

The assumptions for expected failure rates and repair times for figure 1 are listed in Table 1.

A	B	C	D	E	F	G
Given From Failure Data Base						
Item	Mean Time Between Failure	MTBF Units	Failure Rate	Mean Time To Repair	Labor + Expense	Materials/ Repair
			failures/hr	hrs/failure	$/hr	$/failure
Carrier Gas	12	yrs/failure	9.51E-06	1.0	50.00	100.00
Sample Injection Device	9	days/failure	4.63E-03	0.5	50.00	5.00
Spiral Column	26	wks/failure	2.29E-04	6.0	50.00	1000.00
Oven	10	yrs/failure	1.14E-05	24.0	50.00	5000.00
Detectors	30	days/failure	1.39E-03	3.0	50.00	200.00
Amplifiers	6	yrs/failure	1.90E-05	10.0	50.00	500.00
Data Recorders	25	wks/failure	2.38E-04	4.0	50.00	500.00
Signals For Action	4	yrs/failure	2.85E-05	8.0	50.00	200.00
Effluent Stream Action	5	yrs/failure	2.28E-05	8.0	50.00	300.00
Overall System-->	152.0	hrs/failure	6.58E-03	1.474		

A, B, C, E, F, G = Given
D = 1/B corrected for hours Availability = MTBF/(MTBF+MTTR) = 99.04%

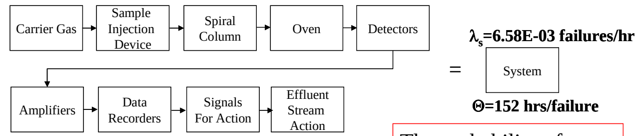
Table 1: Failure Rates & Repair Times For Gas Chromatograph Reliability Model

In Table 1, availability is high (99.04%) as the failed system is quickly restored to service. Reliability is low (R=33.107%) even for a very short, one week, mission time because of frequent failures (MTBF = 152 hours/failure) with quick repairs (MTTR = 1.474 hours).

The most failure prone devices (i.e., highest failure rates) in Figure 1 and Table 2 lack redundancy. They are Achilles heels for analyzer reliability and should be candidates for improvement or redundancy to reduce analyzer system failures.

Figure 2 shows details of the reliability model.

If figure 2 is measured on a mission time of one month, or one year, or a five year basis, the reliability values can be miniscule because of the high failure rates for the system.



$$R_s(t) = \prod_{i=1}^{i=n} R_i = R_1 * R_2 * R_3 \ldots R_n = e^{-\lambda_s * t}$$

$$\lambda_s = \lambda_1 + \lambda_2 + \lambda_3 \ldots \lambda_n$$

The probability of operating for one week without failure is:
$R = e^{-(6.58E-03)*168} = e^{-1.1054}$
= **33.107%,** or p.o.f
UR = 1 – R = **66.893%**

Figure 2: Gas Chromatograph Reliability For A One Year Mission

Failure costs are shown in Table 2.

	H	I	J	K	L	M
	Numbers Driven By Reliability & Maintainability					
	Annual Failures	Annual Repair Time	Labor + Expense	Materials/ Repair	Annual Cost	Pareto Rank For Corrective Action
	failures/yr	hrs/yr	$/yr	$/yr	$/yr	
Carrier Gas	0.083	0.083	4.17	8.33	12.50	Do Later
Sample Injection Device	40.556	20.278	1013.89	202.78	1216.67	Do Later
Spiral Column	2.005	12.033	601.65	2005.49	2607.14	2
Oven	0.100	2.400	120.00	500.00	620.00	Do Later
Detectors	12.167	36.500	1825.00	2433.33	4258.33	1
Amplifiers	0.167	1.667	83.33	83.33	166.67	Do Later
Data Recorders	2.086	8.343	417.14	1042.86	1460.00	3
Signals For Action	0.250	2.000	100.00	50.00	150.00	Do Later
Effluent Stream Action	0.200	1.600	80.00	60.00	140.00	Do Later
Overall System-->	57.613	84.904	4,245.18	6,386.13	10,631.31	

H = D*8760hrs/yr ←Failures
I = H*E ←Time
J = F*I
K = H*G ←Money
L = J + K
M = Separates the vital few $ issues in column L from the trivial many

Table 2: Analyzer Failure Costs From Figure 1 Driven By Table 1 And Figure 2

Appropriate production losses due to instrument failures must be included and likewise damage to the process from absence of the analyzer**,** however, they are **not** included for this particular simple case in Table 2. Notice the action list in Table 2 is based on "lost" money and not the incidence of failures.

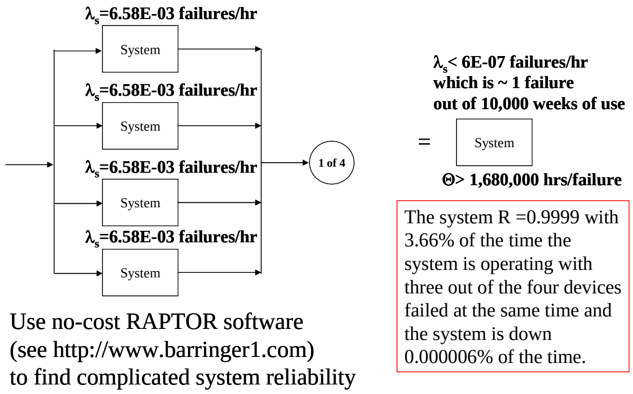
To achieve better analyzer performance without affecting the production system, two or more instruments (and/or redundancy of high failure rate components) may be required to permit survival without individual analyzers compromising the production system integrity.

Simultaneous operation of four analyzers (where only 1 analyzer must survive for success) is described in Figure 3.

Of course four simultaneous instruments require larger capital investments and larger maintenance costs for sustaining the analyzers to achieve the greater reliability and consequently lower system failure rates.

The RAPTOR model used the string of individual blocks from Figure 1 along with the data shown in Table 1 for the Monte Carlo simulation symbolized in each of the small system single blocks in Figure 3.

Figure 3: Reliability of "M Out Of N" System



Use no-cost RAPTOR software (see http://www.barringer1.com) to find complicated system reliability

The model was run for a one week interval and the simulation was repeated 10,000 times to produce the numbers shown in Figure 3. Many replications are required because the use of random numbers results in a different outcome from each simulation. From the noise of the individual simulations comes a clear signal for expected performance during a Monte Carlo simulation.

The number of simultaneous analyzers employed in operation depends upon instrument failure rates, repair rates, consequence of failures, and capital investment. Thus the entire issue is typical of most reliability problems: it is all about time and money which is driven by technical facts to make decisions.

WEIBULL FAILURE DETAILS

An end-user presented oxygen analyzer failure data for review of failures. The data had 11 failure modes from "would not span" to "cell dead". See Table 3 for the raw data.

Instrument--> Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
10/12/2001																								cell							
10/14/2001																		cell													
10/23/2001				cell																											
11/6/2001															cell																
1/22/2002																												cell			
2/8/2002																											cell				
3/4/2002																				cell											
3/25/2002		cell	cell																												
4/2/2002					cell	cell																									
4/22/2002	cell														cell	cell															
5/1/2002								cell																							
5/9/2002					cell																										
5/20/2002			cell							cell				cell	cell																
5/30/2002																		cell													
6/8/2002										cell																					
6/16/2002														cell																	
6/17/2002						cell																									
7/21/2002	cell																														
8/9/2002																														cell	
8/12/2002																								cell							
8/19/2002									cell	cell																					
9/6/2002																					cell										
9/26/2002																						cell									
9/29/2002																				cell											
10/7/2002							cell			cell																					
10/13/2002																						cell									
10/14/2002			cell																												
10/27/2002											cell																				
11/6/2002													cell																		
11/12/2002																												cell			
11/19/2002																		liquid													
11/26/2002																		liquid													
11/27/2002																											wont span				
11/29/2002						not cell - wiring																									
12/1/2002																		liquid													
12/3/2002																			new analyzer												
12/31/2002									cell																						
2/6/2003																			new cell chang'd with electronics												
2/25/2003					wont span																										
3/25/2003		v. slow																													
3/27/2003																failing (diag)															
4/21/2003			cell	cell								cell		cell																	
4/22/2003	cell						cell	cell																							
4/24/2003																							cell								
5/17/2003	wont span																														
5/21/2003												drifting																			
6/9/2003											cell																				
7/14/2003						cell																									
7/27/2003				wont span																											
8/5/2003																		cell													
8/7/2003														wont span																	
8/8/2003																															cell
8/11/2003																cell															
8/16/2003																							cell								
8/23/2003					slow	slow																									
8/26/2003																													dead		
9/8/2003						dead																									
9/11/2003											"bad"																				
9/30/2003			slow	slow																										dead	
10/1/2003				cont. drift				wont span																							
10/12/2003																					cell										
10/19/2003																				dead											

349 days suspension

304 days age-to-failure

Cum Days	Cum Failures																															Total	Average Failures
737	4	2	5	5	4	6	2	3	2	4	3	2	1	4	3	3	0	6	2	3	2	2	2	2	0	0	2	2	1	2	1	80	2.581
Days/failure	184	369	147	147	184	123	369	246	369	184	246	369	737	184	246	246	>737	123	369	246	369	369	369	369	>737	>737	369	369	737	369	737	285.6	

Table 3: Raw Data For Oxygen Detectors In Similar Service

This specific life analysis was for a failure mode of “cell”. This failure mode occurs when chemicals in the cell were depleted and would no longer function.

All other 10 reasons for failures and the cells that still had remaining life were considered suspensions. Data from Table 3 has been converted to age-to-failure data in Table 4 along with the suspensions.

Furthermore, the data with suspensions of life greater than 180 days and actual reported life greater than 180 days were considered incorrect reports because data was missing from Table 3.

The data older than 180 days was not used because of reporting errors.

Reliability data must be carefully accumulated using consistent failure criteria and age-to-failure data along with suspended ages which are carefully recorded. Each failure mode must be analyzed separately.

See Table 5 for failure data used for the Weibull plot. Suspension (unfailed age, and failure from different failure modes) carry the label of a “-“ sign. Age-to-failure is shown with positive numbers.

Instrument--> Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
10/12/2001																															
10/14/2001																		-2													
10/23/2001				-11																											
11/6/2001															-25																
1/22/2002																												102			
2/8/2002																											-119				
3/4/2002																				-143											
3/25/2002		-164	-164																												
4/2/2002					-172	-172																									
4/22/2002	-192														167	-192															
5/1/2002								-201																							
5/9/2002					37																										
5/20/2002			56							-220				-220	28																
5/30/2002																		228													
6/8/2002										19																					
6/16/2002														27																	
6/17/2002						76																									
7/21/2002	90																														
8/9/2002																														-301	
8/12/2002																								304							
8/19/2002									-311	72																					
9/6/2002																					-329										
9/26/2002																						-349									
9/29/2002																				209											
10/7/2002							-367			49																					
10/13/2002																						17									
10/14/2002			147																												
10/27/2002											-380																				
11/6/2002													-390																		
11/12/2002																												294			
11/19/2002																		-173													
11/26/2002																		-7													
11/27/2002																											-292				
11/29/2002						165																									
12/1/2002																		-5													
12/3/2002																			-417												
12/31/2002									134																						
2/6/2003																			-65												
2/25/2003					-292																										
3/25/2003		-365																													
3/27/2003																-339															
4/21/2003			189	-545								-556		309																	
4/22/2003	275						197	356																							
4/24/2003																							-559								
5/17/2003	-25																														
5/21/2003												-30																			
6/9/2003											225																				
7/14/2003						227																									
7/27/2003				-97																											
8/5/2003																		247													
8/7/2003														-108																	
8/8/2003																															-665
8/11/2003																137															
8/16/2003																							114								
8/23/2003					-179	-40																									
8/26/2003																													-683		
9/8/2003						-16																									
9/11/2003											-94																				
9/30/2003			-162	-65																										-417	
10/1/2003				-1				162																							
10/12/2003																					401										
10/19/2003	-155	-208	-19	-18	-57	-41	-180	-18	-292	-377	-38	-151	-347	-73	-517	-69	-737	-75	-320	-385	-7	-371	-64	-433	-737	-737	-326	-341	-54	-19	-72

Table 4: Age-To-Failure For “Cell” Failures Where “-“ Signifies Suspended Data

Most of the data for Table 5 contains censored information from unfailed units or units that have failed with a different failure mode. This complexity is a common occurrence for reliability data. If the suspensions are not recorded correctly, then the answers from the Weibull analysis will be incorrect!

Table 5: "Cell" Data For Weibull Analysis

Cell Failures		
Suspensions	Suspensions	Failures
-180	-64	17
-179	-57	19
-173	-54	27
-172	-41	28
-172	-40	37
-164	-38	49
-164	-30	56
-162	-25	72
-155	-25	76
-151	-19	90
-143	-19	102
-119	-18	114
-108	-18	134
-97	-16	137
-94	-11	147
-75	-7	162
-73	-7	165
-72	-5	167
-69	-2	
-65	-1	
-65		

Remember data for Table 5 is truncated. The truncation is based on engineering judgment that any calculated age of a failure or a suspension greater than 180 days only occurred because data was missing from the tabulation.

Table 5 is used to make the probability plot in Figure 4.

Figure 4 shows the Weibull probability plot obtained by use of WinSMITH Weibull software (Fulton 2003) on the data in Table 5. The single point estimate of cell life given by the eta value is 201 days. The beta value on the Weibull plot is > 1 which tells the failure mode is wear-out which is in concert with the end user's perception that the cell mode of failure should be a physical wear out phenomena.

In Figure 4, the goodness of fit criteria is r^2, the coefficient of determination, and it exceeds the critical value which shows the curve fit is valid at 90% confidence. The symbols n/s says the data set has 59 data points of which 41 are suspensions.

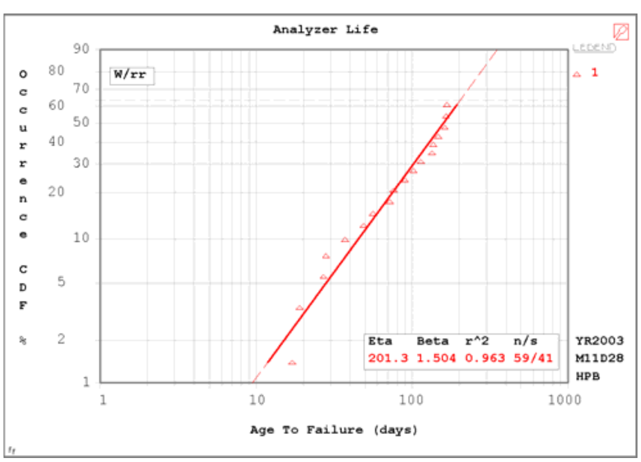


Figure 4: Weibull Probability Plot

Of course, the plot in Figure 4 says 43% of the life data will be greater than 180 days, 10% of the data can live longer than 350 days, and 1% of the data can survive longer than 555 days.

If we include "old" data and old suspensions in the data set, the Weibull failure mode is still wear out, beta = 1.28, and the characteristic life, eta = 469.1 days. Which analysis is correct?—the issue can be argued, however, better data recording of ages and suspensions for a given failure mode can answer the question to avoid arguments.

Why is it important to quantify failures by Weibull analysis? Use the Weibull characteristics of failure to improve accuracy of the reliability model. Because we have a wear out failure mode we can now use the Weibull information to aid in replacement decisions based on the cost for a planned replacement and unplanned replacement.

Suppose the cost for a planned replacement is \$2000 and the total cost for an unplanned replacement is \$8000. Using the Weibull results, we can find the optimum replacement interval where cost is the least is 167 days as shown in Figure 5.

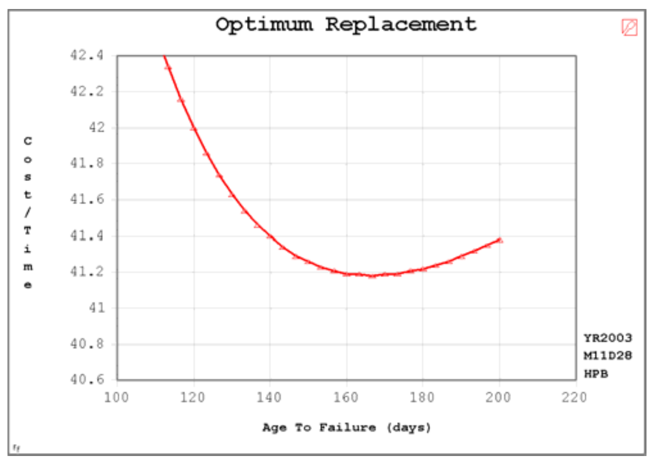


Figure 5: Optimum Replacement Interval = 167 days

Note the sensitivity of the cost versus time curve in Figure 5 which suggests a small gain by use of optimum replacement. However, and a more practical strategy would simply be to run to failure—particularly in light of the possibility that the detectors may demonstrate life longer than 180 days. As another case, if the unplanned costs were only \$6000, no optimum replacement exists. Figure 5 helps reduce arguments and wasted time by endless discussions about the most effective replacement strategies. The curve in Figure 5 was made using WinSMITH Visual software Fulton (2003).

SUMMARY

Reliability models can be used to predict the failures expected and the maintenance demands for sustaining resources along with the decision making process for the quantity of instruments needed to make life cycle cost decisions. The decisions can be fact based using reliability data.

When failure data is analyzed using reliability technology, life of components can be quantified along with failure modes such as infant mortality, chance failures, and wear out failure modes.

When the failure modes and Weibull life are connected with planned/unplanned costs, better maintenance decisions can be implemented based on facts rather than endless arguments about the right strategy to be employed for cost effective maintenance decisions.

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Reliability, engineering, and manufacturing consultant. Author of the basic reliability training course **Reliability Engineering Principles,** a practical financial evaluation course **Life Cycle Costs**, and **Process Reliability** which is a high level method of assessing and understanding process reliability. More than forty years of engineering and manufacturing experience in design, production, quality, maintenance, and reliability of technical products. He is a contributor to **The New Weibull Handbook**, a reliability engineering text published by Dr. Robert B. Abernethy. Barringer is named as inventor in six U.S.A. Patents and numerous foreign patents. He is a licensed Professional Engineer in Texas. His education includes a MS and BS in Mechanical Engineering from North Carolina State University, and he participated in Harvard University's three week Manufacturing Strategy conference. Other details and technical papers on a variety of reliability and life cycle cost issues are available at **http://www.barringer1.com** for other background details or send e-mail to **hpaul@barringer1.com**.

December 2, 2003