Setting the Stage for Effectively Managing Warranty Improvement

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Abstract

Effective management of warranty improvement is best accomplished by cross-organizational partnership and contribution. Agilent Technologies utilizes this form of partnership to manage and drive reliability improvement. Key partner organizations include Service, Logistics, Information Technology, Failure Analysis Labs, Manufacturing and Engineering. A structured program approach utilizing the key process elements of reliability monitoring, data collection, data analysis, prioritization/commitment of resources, and corrective action is employed. A critical success factor for assuring effective warranty management is shared ownership of accountabilities by senior leaders. This paper describes how these functions work as a team to effectively manage warranty.

Just as maintaining and improving warranty requires continuous investments, reliability improvement processes themselves should undergo continuous scrutiny and upgrades in order to maintain a leadership position in your business. For example, reliability metrics such as the widely used Annualized Failure Rate can be extremely sluggish to respond to changes in the product's reliability over the course of its manufacturing life cycle. The iFR Method described in this paper has been shown to be effective in providing a more responsive leading indicator of customer-experienced reliability in complex electronic equipment. The method can enable a manufacturer to 1) more quickly take action in response to degradation in product reliability, and 2) avoid costly, unnecessary engineering changes when recent improvements are judged to be effective and adequate.

Background

Agilent Technologies designs, manufactures and markets electronic test and measurement equipment. They sell into markets in more than 170 countries and have a manufacturing presence in every major geography. Agilent's electronic measurement products are highly complex systems where part counts range from a few thousand components to more than 20,000. Many of their products are characterized by long life cycles. When product revisions are considered, it is not uncommon for model numbers to be in manufacturing for more than a decade. Additionally, many products are supported for five years after obsolescence, so it is a business imperative (both from the standpoint of minimizing warranty costs and maintaining high levels of customer satisfaction) that Agilent maintain a robust reliability program.

The Reliability Improvement Process

Agilent utilizes a Reliability Improvement Process (RIP) program to drive warranty improvement. This structured program approach has at its foundation cross-organizational partnership and contribution. The five key elements in the program include:

1) Reliability Monitoring & Detection,
2) Data Collection,
3) Analysis,
4) Prioritization & Resource Commitment, and
5) Corrective Action.

Reliability follows the 2nd Law of Thermodynamics: Disorder (Unreliability) occurs without the application of Energy (Corrective Action). Because of this characteristic, the RIP program must be managed as a continuous investment in maintaining and improving warranty.

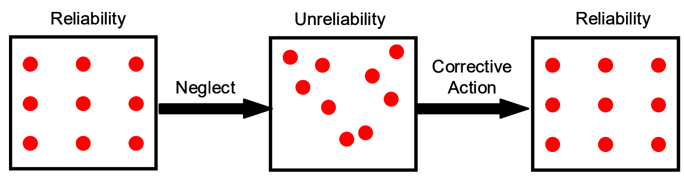

Figure 1. Reliability and the 2nd Law of Thermodynamics

The RIP program can not be successful without active participation (investment) by multiple organizations and shared ownership of accountabilities by senior leaders. These organizations provide critical data, process and system support of the RIP program. Key organizations include Service, Logistics, Information Technology (IT), Failure Analysis (FA) Labs, Manufacturing, Engineering, Customer Support and Procurement. To understand how the pieces in the RIP puzzle fit together, a construct is shown in Table 1.

Table 1. Organizational and system support of the RIP Program

	Reliability Monitoring & Detection	Data Collection	Analysis	Prioritization & Resource Commitment	Corrective Action
Organizations	• Service • IT	• Service • Logistics • IT	• Customer Support • Engineering • Manufacturing • Failure Analysis Lab	• Management • Engineering • Customer Support • Manufacturing	• Engineering • Manufacturing • Procurement
Data	• Units Under Warranty • Warranty Failures	• Failed Products • Failed Parts • RMA Details	• Root Cause Analysis • Most Probable Cause	• Corrective Actions Plans • Corrective Action Results	• Corrective Action Reports • Fail Rate projections
Processes/Systems	• CRM • ERP • Product Data • Warranty Data WH	• Factory Repair Program • Parts Return Program • Warranty Reporting System	• 7 "Original" Quality Tools • 7 "New" Quality Management Tools		

Reliability Monitoring & Detection

The eyes and ears of the RIP program are warranty fail rate measures. The Service organization is responsible for collecting and entering field failure details into Agilent's CRM system. This information, along with product detail information from Agilent's ERP and Product Data systems, is fed into a warranty data warehouse. Key data driving warranty failure rate calculations include units under warranty and warranty failure events. Additional critical information includes model number, serial number, fail age, customer comments, repair details and parts replaced. IT plays a critical role in system development, maintenance and enhancement.

Data Collection

When warranty fail rates measures begin to edge upward, the RIP program kicks into high gear. The key here is collection of data so that root cause can be determined. Service, Logistics and IT play pivotal roles. In terms of information value, return of failed products, return of failed parts and return of Return Material Authorization (RMA) details, in that order, are important. Service and Logistics play crucial roles in the expedited return of failed products for failure analysis. When that is not possible, return of failed parts is the next best source of valued failure information. Lastly, RMA data is the next best source for understanding why the product failed. IT helps maintain and improve the warranty reporting system.

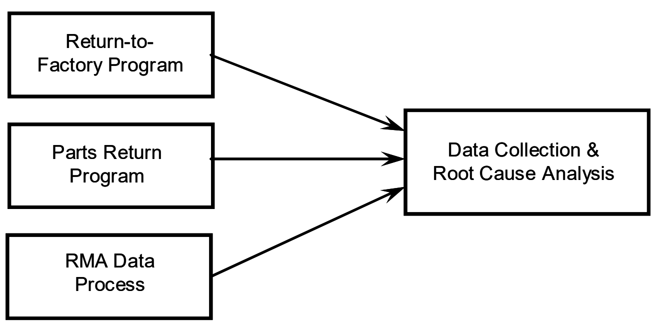

Figure 2. Data collection processes for driving warranty improvement.

Analysis

RMA data is carefully analyzed by customer support engineers and production engineers. Based on customer comments and repair details entered by repair technicians, most probably cause is assigned. Pareto charts of replaced parts, most probable cause and repair class codes are created to establish trends and priorities.

Returned product and parts are collected at the factory and prioritized for failure analysis based on recent trends. Manufacturing technicians and production engineers perform failure analysis at the system and subassembly levels. In some cases, root cause down to the component part can be determined at this point. When this is not possible, subassemblies are sent to internal FA Labs or external suppliers for more detailed lower level analysis to determine root cause.

Prioritization & Resource Commitment

Depending upon the situation, RIP team meetings are held weekly or bi-weekly to review warranty metrics, Pareto charts, failure mode summaries, trend charts and failure analysis details. Core RIP team members include production management, production engineers, manufacturing technicians and assemblers, and customer support engineers. Extended RIP team members consisting of failure analysis engineers, procurement engineers, and R&D engineers may be called upon to participate. The purpose of the RIP team meetings is to make informed management decisions regarding where reliability improvement resources should be allocated, and to review results of those activities.

Corrective Action

Based on prioritization and commitment decisions made by management, engineering is engaged to make changes in design, material and processes to eliminate failure modes. In addition to engineering changes, other actions might include containment plans to isolate, return and/or rework defective lower level material and finished goods inventory.

Internal production defect measures and warranty failure metrics are closely monitored to verify that corrective action taken to eliminate root cause was indeed effective.

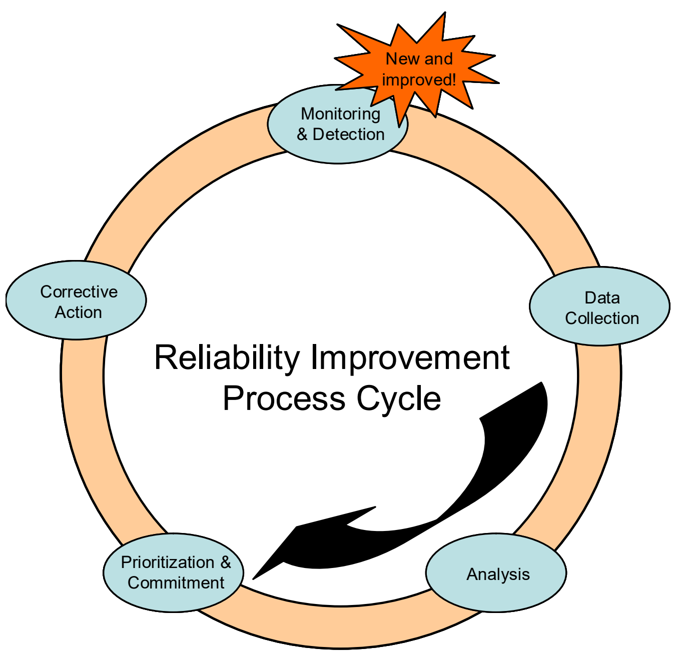

Figure 3. The Reliability Improvement Process cycle.

Improved Monitoring of Reliability

Agilent utilizes a non-parametric AFR (Annualized Failure Rate) metric for monitoring warranty failure rates. However, the AFR metric can be very sluggish to respond to changes in customer-experienced reliability. When investments to improve reliability culminate in the implementation of an engineering change, it can take as many as nine to 12 months before improvement is observed in the AFR. Equally important, degradation in reliability may be quickly detected by customers but it may take several months before a change is observed by internal AFR measures. What is needed is a more responsive metric for monitoring and detecting changes in reliability, i.e. a "new and improved" warranty fail rate process as depicted in Figure 3.

The "instant Failure Rate" (iFR) is a parametric-based measure developed for the express purpose of providing much quicker feedback of changes in a product's reliability. This paper will now explain the iFR Method through analysis of actual field failure data. The paper will also demonstrate how a balance is struck between selecting iFR variables that yield the best possible combination of quick reliability feedback, effective AFR predictive power and narrow confidence bounds.

> Note: The term "iFR" as used in this paper should not be confused with the reliability hazard rate[1], given by
>
> $$h(t) = \frac{\mathrm{f}(t)}{\mathrm{R}(t)}$$
>
> where *h(t)* is the true instantaneous failure rate, *f(t)* is the frequency of failures function, and *R(t)* is the reliability function representing the probability that the product will survive until time *t*. In this paper, "iFR" is meant to signify a metric that is much more responsive than the non-parametric AFR in measuring the reliability of products currently being shipped.

Annualized Failure Rate Metrics

A widely used method for measuring reliability of electronic equipment is through the calculation of field failure rates using the AFR. There are countless different variations on such non-parametric methods, but they generally rely upon simple calculations involving the number of failures and the size of the installed base.[2]

The advantages of such methods are their simplicity and ease of understanding. No special software or graphing paper is required to make the calculation. The computation is straightforward and can be performed by someone who is not familiar with reliability statistics. The calculation is quick, simple and can be easily explained to the layperson. For these reasons, AFR is widely used in industry to measure the reliability of electronic equipment.

The disadvantages of such AFR methods are several. These methods do not allow for quantification of confidence bounds. Additionally, many of such metrics make the potentially false assumption that the underlying failure rate is constant over time. These methods also do not allow for conditional probability calculations.

Finally, a major disadvantage of AFR methods is that they can be sluggish to respond to changes in product reliability (both degradation and improvement) during the product's manufacturing life cycle. The iFR Method provides a solution to this important shortcoming associated with sluggish response time.

The iFR Method

The method is based on parametric techniques involving reliability statistics and principles. Reliability statistics are well documented in textbooks and the literature.[3,4,5]

By using the iFR Method, changes in the reliability of complex electronic measurement equipment can be detected by as many as four to six months earlier than would be otherwise possible using some conventional AFR methods.

<u>Keys to Success</u>

The keys to the success of the iFR Method include selecting a shipment evaluation window that strikes the optimum balance between:

1) providing timely feedback of reliability changes,
2) detecting the occurrence of new failure mechanisms,
3) providing acceptable confidence bounds,
4) minimizing reliability false alarms, and
5) providing useful predictive power for anticipating eventual changes in AFR.

Through analysis of shipment and failure data associated with more than a dozen different products involving complex electronic measurement equipment, the iFR Method has been effective in predicting future AFR trends by using a shipment evaluation window in the range of four to six months.

Complex electronic measurement equipment is characterized by having between a few thousand electronic components and more than 10,000 electronic components, while at the same time having relatively few mechanical components. With the advancement in design and manufacturing technology over the past 10-20 years, electronic components have the distinguishing feature of typically exhibiting constant failure rates or improving failure rates (so-called "infant mortality") over time. Eventually these parts will enter a wear-out phase which is marked by a rapidly increasing fail rate, however for electronic components this phase is generally well beyond the normal expected operating life of the end product. Therefore owners of complex electronic measurement equipment will rarely experience such electronic component failures.

Mechanical parts are susceptible to wear-out failure mechanisms. However, their relatively low numbers in electronic measurement equipment and recent advances in their reliability have resulted in products where customer-experienced failure of mechanical parts is fairly small over the expected operating life.

These observations, coupled with the selection of an optimum iFR data analysis shipment window, mean that it is possible to predict changes in traditional AFR reliability metrics by as many as six months earlier than when the AFR metric would show the change.

Definition of the iFR Method

1) The Shipment Evaluation Window is defined to be the number of consecutive months containing product shipments that the reliability analyst wishes to consider in the failure rate prediction.
2) The iFR Reporting Month is defined to be the last month of the Shipment Evaluation Window.
3) Data processing and metric calculation begins one month after the end of the Shipment Evaluation Window. This is referred to as the Calculation Date.
4) On the Calculation Date, collect qualifying shipment records from the specified Shipment Evaluation Window.
5) On the Calculation Date collect failure records (namely failure age) from qualifying shipments records.
6) Calculate ages of qualifying shipments that have not yet failed as of the Calculation Date.
7) Enter ages of failed products and ages of unfailed products into a parametric reliability data analysis tool.
8) Select the life data distribution that best fits the data. For distributions that equally fit the data, selecting the distribution that yields the lowest fail rate generally provides the best predictive result.
9) Calculate the percent of failed products expected after one year of operation. This is the iFR for that Reporting Month.
10) Plot the iFR by Reporting Month over time and use the trend line to predict changes in the associated AFR.

Refer to Figure 4 for a timeline of iFR Method events.

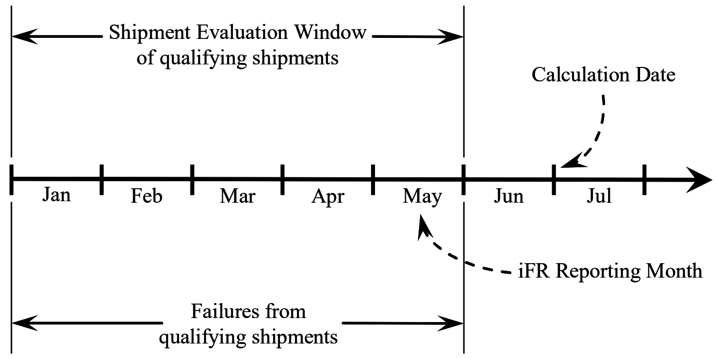

Figure 4. Timing of 5-month iFR calculation events

Optimizing the iFR Method

Agilent designs and manufactures complex electronic test and measurement equipment. It is common for such equipment to have 10,000 or more electronic components. Typically the equipment is constructed of several digital and analog printed circuit assemblies, hybrid microcircuit assemblies, power supply, disk drive, CD-ROM, keypad assembly and display. While the equipment does contain some mechanical parts, the vast majority of components are electronic.

The iFR Method was optimized by analyzing actual fielded data of a complex electronic measurement system.

> Note: The data presented here has been disguised but the results and conclusions are the same.

Field failure data spanning more than three years was studied using the iFR Method. Shipment windows consisting of six different sizes were initially analyzed: two months, four months, six months, eight months, ten months and twelve months. Utilizing parametric methods, the iFR was calculated for 30 successive reporting months. These data points were plotted to evaluate the relationship between the calculated iFR and the product's eventual AFR.

Impact of Shipment Window Size

In looking at Figure 5, at the one extreme we see that using a wide 12-month shipment evaluation window results in an iFR that is an excellent predictor of the eventual AFR. However, the disadvantage of the 12-month shipment window is that the practitioner must wait a full year before the calculation is made. As a result, such a wide evaluation window makes this choice of little value.

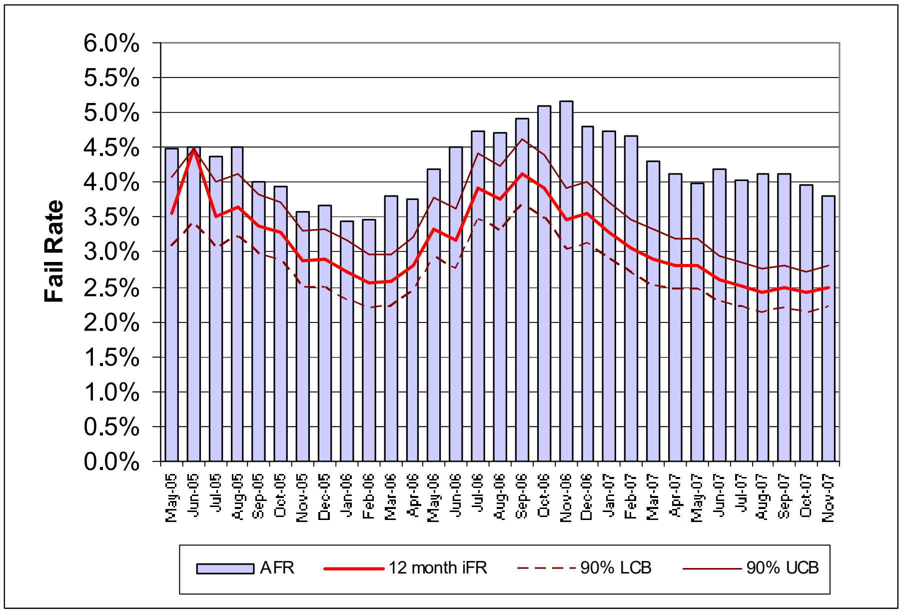

Figure 5. 12-month shipment evaluation window

At the other the extreme shown in Figure 6, we see that a narrow 2-month shipment evaluation window yields a very responsive metric that can be calculated with very little delay. Unfortunately, such a short evaluation window can result in some wild month-over-month fluctuations, numerous false alarms and a generally poor predictor of the eventual AFR (as will be discussed later in this paper).

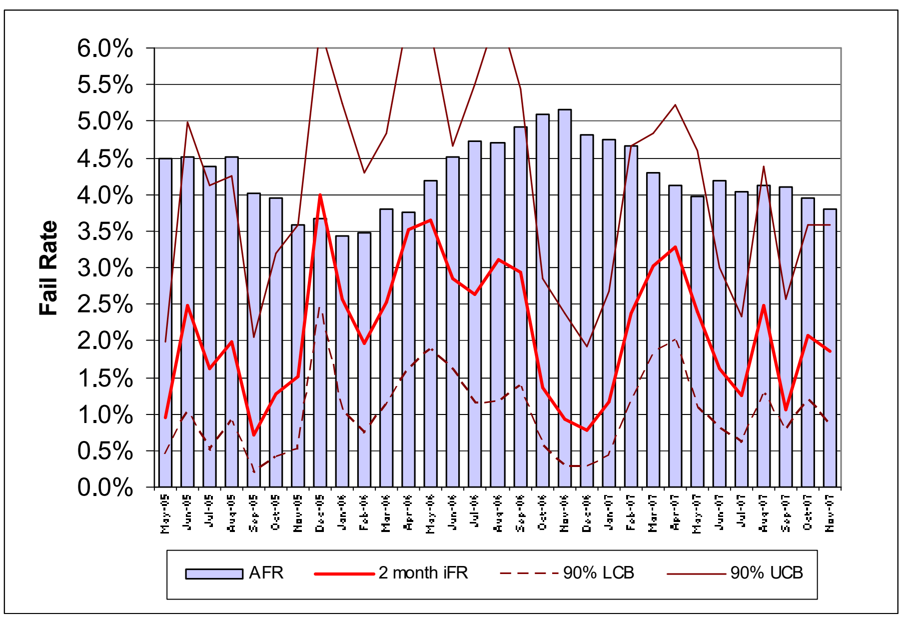

Figure 6. 2-month shipment evaluation window

In examining the other shipment evaluation windows as shown in Figures 7 through 9, we see that an evaluation window between four and six months seems to offer the best balance between predictive power of the iFR, stability and shortest delay in the making the iFR calculation. The iFR for a 10-month shipment evaluation window was calculated but is not presented here for brevity; its shape is very similar to that of the 8-month shipment evaluation window.

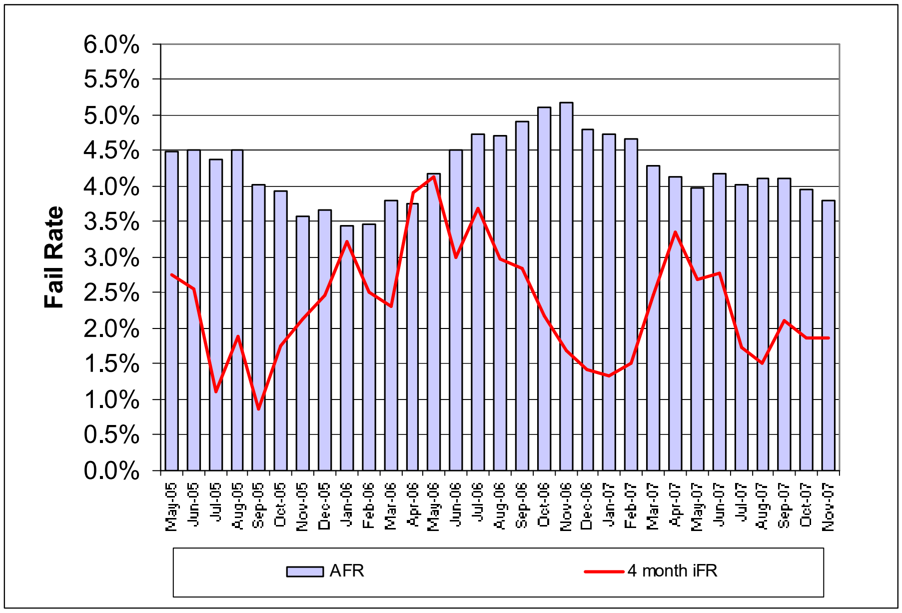

Figure 7. 4-month shipment evaluation window

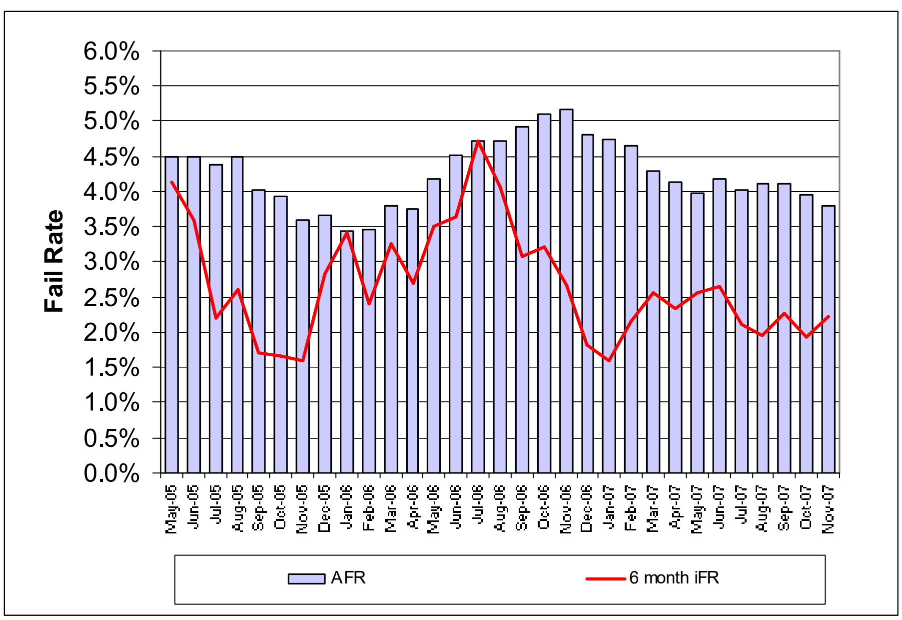

Figure 8. 6-month shipment evaluation window

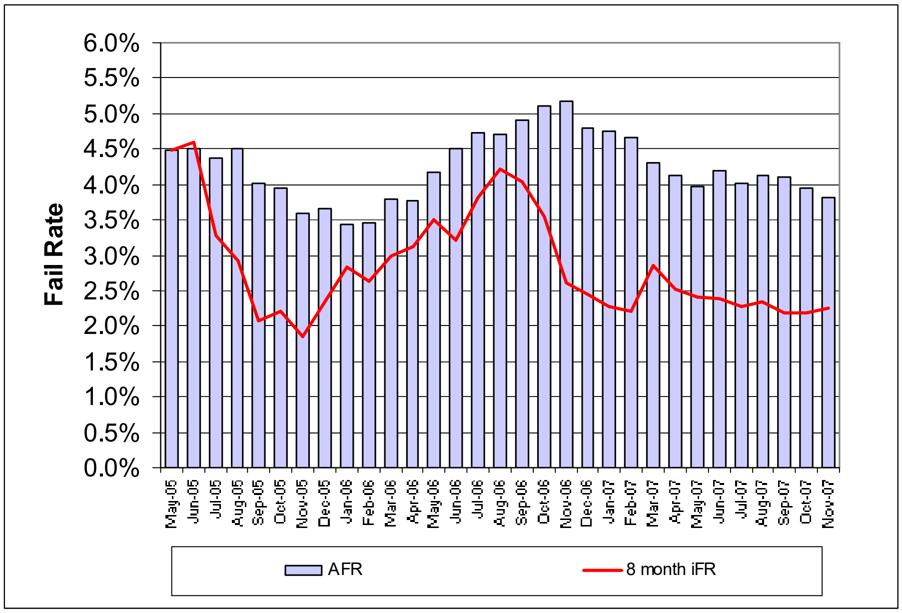

Figure 9. 8-month shipment evaluation window

These graphs show a steep decrease in iFR in mid-2005. At the end of 2004 the engineering team discovered that one of the components in an attenuator assembly degraded over time. After evaluating alternative components, an improved device was selected and implemented in early 2005. To the relief of the engineering team, the AFR subsequently dropped as predicted by the iFR and the design improvement was affirmed.

The initial increase in iFR observed at the end of 2005 accurately predicted an associated increase in AFR during the first half of 2006. A Pareto analysis of failed assemblies showed increasing failure rates on multiple printed circuit assemblies. Failure analysis of these PCA's revealed a fabrication problem with a series of tantalum capacitors purchased from the same supplier. Components from other suppliers were evaluated and devices with improved reliability were implemented in mid-2006. The iFR gave advance notice of the problem and it confirmed that the solution would be effective.

To further optimize predictive results, the iFR Method was fine tuned by calculating failure rates using a 5-month shipment evaluation window. The results are shown in Figure 10.

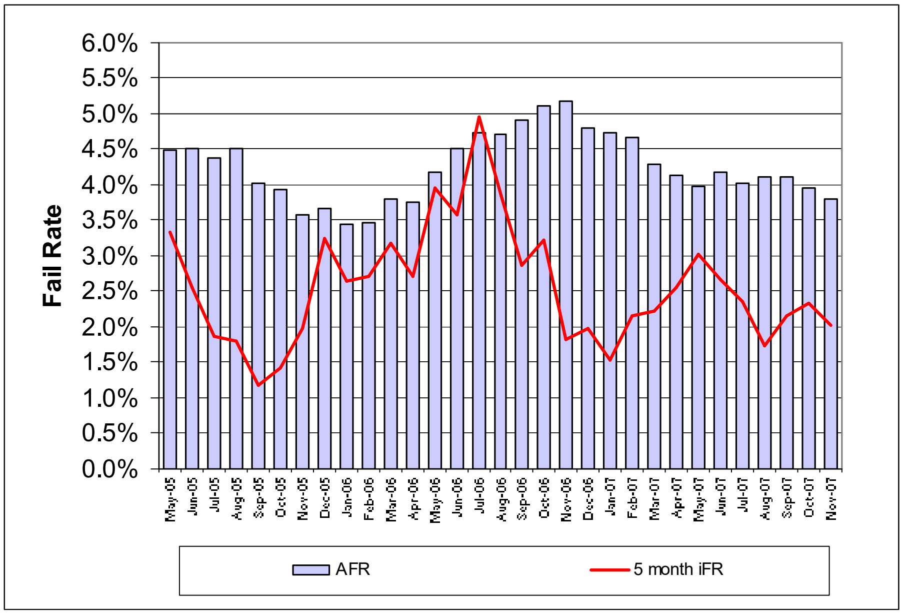

Figure 10. 5-month shipment evaluation window

Confidence Bounds

Another important aspect when considering what size of evaluation period to select is the width of the iFR confidence bounds. Confidence bounds on failure rates are inversely proportional to the number of field failures observed. Consequently, narrowest confidence bounds will occur with the largest shipment evaluation windows.

For a failure process that follows the exponential distribution, the two-sided upper limit on the failure rate is given by

$$\lambda_U = \frac{\chi_{\alpha/2,2r+2}}{2T},$$

where χ is the Chi square distribution, α is the significance level, $2r+2$ is the degrees of freedom (r is the number of failures observed) and T is the total product exposure time.[5]

The two-sided lower limit on the failure rate is given by

$$\lambda_L = \frac{\chi_{1-\alpha/2,2r}}{2T}.$$

Larger shipment evaluation windows will provide greater precision in the metric. Again, we have the tradeoff between using small shipment windows (quick reliability feedback) and larger shipment windows. The affect of evaluation window size on confidence bounds can be clearly seen in Figures 5 and 6.

The confidence bounds for shipment evaluation windows of four months, five months and six months were also calculated (not presented here for brevity). These confidence bounds were all roughly the same and therefore did not play a significant factor in selecting the optimum shipment evaluation window.

iFR Predictive Power

We want a shipment evaluation period that affords the best possible predictive power (using iFR to predict the eventual AFR) while at the same time minimizing calculation delay time and confidence bound widths. A correlation analysis using linear regression was performed where iFR and eventual AFR were compared using the previously described shipment evaluation windows. For each shipment evaluation window, correlation coefficients were calculated using five different iFR lead times. iFR lead time represents the amount of advance notice that the iFR metric provides with respect to predicting the eventual AFR number. Results of this analysis are shown in Table 2.

Table 2. Correlation coefficients to assess the predictive power of the iFR.

Shipment Window Size (months)	AFR Advance Warning Lead Time (months)								
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2					0.48	0.57	0.59	0.47	0.34
4				0.53	0.67	0.68	0.65	0.53	
5			0.55	0.74	**0.79**	0.70	0.60		
6		0.39	0.60	0.71	0.68	0.53			
8	0.45	0.58	0.70	0.64	0.49				
10	0.71	0.69	0.72	0.62					
12	0.71	0.67	0.61						

Similar to a long range weather forecast, iFR predictive accuracy declines as we attempt to predict further into the future about what the AFR will eventually be. We also see that the iFR predictive power improves with larger shipment evaluation windows. Larger evaluation windows tend to yield better results because 1) greater customer-use time (i.e. exposure time) provides for more latent failure mechanisms to manifest themselves, and 2) larger data sets drive smaller random variation (confidence bounds) in the calculated iFR.

It would make little sense to use a shipment evaluation window of 10 or 12 months because one would have to wait for nearly one year in order to make an accurate statement about what the AFR is likely to do in the following month.

In this example, we see that the sweet spot for predicting AFR (highest predictive power, shortest iFR calculation delay and acceptable confidence bounds) is achieved by selecting a five month shipment evaluation window. This results in an optimum AFR lead time indicator of four months. Slightly inferior, but nevertheless useful, results can be obtained with four and six month shipment evaluation windows.

Limitations

Methods for predicting field failure rates are based on failure mechanisms that have already manifested themselves. If a specific failure mechanism, e.g. the wear out of a disk drive bearing, has not already presented itself in the data, then such methods have no way of knowing that the failure mechanism can occur. As such, predictive methods would not be effective on products that have failure mechanisms occurring beyond the edge of the shipment evaluation window.

While complex electronic measurement equipment is typically constructed of electronic components that exhibit constant or decreasing failure rates, there are occasions when such components may exhibit an increasing failure rate during the product's normal expected operating life. Likewise, one of the product's handful of mechanical parts may enter a wear out phase unexpectedly early. Either of these two scenarios would likely not provide for an accurate AFR prediction based on only a few months of early field data used in the iFR Method.

Conclusions

Effective management of warranty improvement is best accomplished by cross-organizational partnership and contribution. Key partner organizations include Service, Logistics, Information Technology, Failure Analysis Labs, Manufacturing and Engineering. A structured program approach utilizing the key process elements of reliability monitoring, data collection, data analysis, prioritization and commitment of resources, and corrective action is employed. A critical success factor for assuring effective warranty management is shared ownership of accountabilities by senior leaders.

Just as maintaining and improving warranty requires continuous investments, reliability improvement processes themselves should undergo continuous scrutiny and upgrades in order to maintain a leadership position in your business. For example, reliability metrics such as the widely used Annualized Failure Rate can be extremely sluggish to respond to changes in the product's reliability over the course of its manufacturing life cycle. The iFR Method described in this paper has been shown to be effective in providing a more responsive leading indicator of customer-experienced reliability in complex electronic measurement equipment. The method can enable a manufacturer to 1) more quickly take action in response to degradation in product reliability, and 2) avoid costly, unnecessary engineering changes when recent improvements are judged to be effective and adequate.

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Bill Lycette is a Quality & Reliability Program Manager with Agilent Technologies. He has 26 years of engineering experience with Hewlett-Packard and Agilent Technologies, including positions in reliability and quality engineering, process engineering, and manufacturing engineering of microelectronics, printed circuit assemblies and system-level products. Mr. Lycette is an ASQ Certified Reliability Engineer, Quality Engineer and Six Sigma Black Belt.