White Paper

5 Techniques for Reliable Product Design

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It's a common expectation for equipment and appliances to function properly. In fact, we depend on our devices to be reliable, especially for our everyday tasks and responsibilities. What happens when these products fail? We are left disappointed, frustrated and question the brand's reliability and credibility.

Reliability is the probability that a product, equipment or service will perform satisfactorily for a defined period, under normal conditions of use. Reliable products provide a consistent experience for customers who might eventually become loyal brand advocates.

Product failure, warranty costs and liability claims, all have a significant impact on customer satisfaction and a brand's reputation. Organizations that repair or replace their equipment only after it fails spend more time, money, and resources, compared to those that design a reliable product from the very beginning. If companies want to maintain product excellence and customer loyalty, they must consistently work toward reducing the level of product, equipment, and service deficiencies.

According to an article published by Berkley Global Product Recall, the 10 greatest U.S. product recalls of all time have cost companies over $70 billion in damages, and the companies impacted are still recovering as a result of faulty products[1]. Though only a portion of those recalls were reliability-related, this shows how product design plays a crucial role in delivering a dependable product to the market.

Some of the top implications of equipment and product failure result in:

- Downtime, repairs, unplanned maintenance and recalls
- Liability claims
- High warranty costs
- Lack of compliance
- Costs associated with poor quality
- Damaged brand reputation
- Customer churn

To proactively address these implications, it is imperative to design reliable products early in the development stage, rather than finding out later in the hands of the customer. The ideal solution is to implement Design for Reliability techniques throughout the development stage to create robust and compliant products, components, and equipment.

Design for Reliability (DfR) describes a set of techniques and tools that support product and process design from the concept stage through product end-of-life. This method ensures that customer expectations for reliability are fully met throughout the product lifecycle, while maintaining overall low cost for an organization.

In this white paper, we provide insight into the Design for Reliability methodology and how it supports successful product development. We also highlight five techniques and ways to implement them with Minitab Solutions Analytics™, where we provide our software and service solutions to empower organizations to make better business decisions.

Technique 1: Define Reliability Objectives

The first step toward successful product development is to define your reliability objectives.

Depending on product or industry, setting reliability requirements to prevent failure while a product is in use may be based on:

- Cost of Non-Quality (CoNQ)
- Safety
- Compliance with regulatory warranty period
- Voice Of the Customer
- Original equipment, component, or material manufacturer recommendations
- Competition
- Usage conditions including stress, not meeting expectations for normal product usage or the environment

To help you effectively monitor product reliability, the following metrics can be utilized: B10, Mean Time Between Failure (MTBF), warranty costs, and unplanned maintenance costs. These metrics are based on financial impact, customer downtime and failure rates.

MTBF | B10 | € | MTTF | $

To further illustrate this technique, we will begin by highlighting an example of warranty prediction, where a reliability engineer uses Minitab® Statistical Software to predict warranty claims caused by defective refrigerator compressors.

Example: Warranty Prediction[2]

Overview: The engineer collects and analyzes monthly failure data for the previous year and knows that the future production schedule is for 1000 units to be shipped each month. The failure data can be modeled using a Weibull distribution.

Reliability Tool Used: After reformatting the pre-process warranty data, the engineer uses warranty prediction to forecast future warranty claims.

Results: The results in the Summary of Current Warranty Claims table indicate that, of the 12,000 compressors in the field during the data collection period, 69 compressors failed. Based on the estimate obtained using a Weibull distribution, approximately 69 compressors were expected to fail during this time.

Using the Table of Predicted Number of Failures and the Predicted Number of Failures Plot, the engineer can conclude with 95% confidence that the number of additional compressors expected to fail within the next five months is within the interval from approximately 62 to 98 compressors.

To forecast future warranty claims or returns based on historical warranty data, use Warranty Prediction. A warranty analysis uses information about past warranty claims to predict the number and cost of warranty claims in the future. By fitting a distribution to your warranty data, you can estimate the number of expected failures in the next month, year, or other period of time. Using the results of the analysis, you can better allocate resources to address future product failures adequately.

* NOTE * 22 cases were used; 2 cases contained missing values or zero frequencies.

Using frequencies in Frequencies

Distribution Parameters

Distribution	Shape	Scale
Weibull	1.26494	398.062

Maximum likelihood estimation method

Summary of Current Warranty Claims

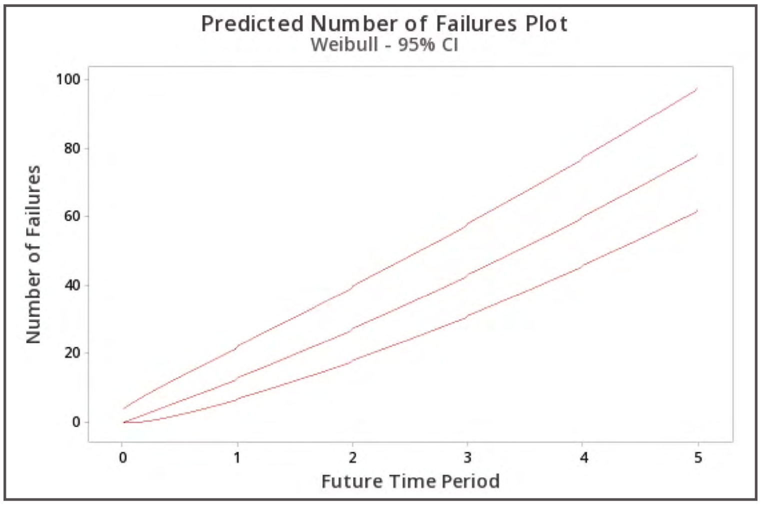
Total number of units	12000
Observed number of failures	69
Expected number of failures	68.5201
95% Poisson CI	(53.2630, 86.7876)
Number of units at risk for future time periods	11931

Production Schedule

Future time period	1	2	3	4	5
Production quantity	1000	1000	1000	1000	1000

Table of Predicted Number of Failures

Future Time Period	Potential Number of Failures	Predicted Number of Failures	95% Poisson CI Lower	95% Poisson CI Upper
1	12931	13.1073	7.0000	22.3660
2	13931	27.4930	18.1933	39.8678
3	14931	43.1798	31.2722	58.1271
4	15931	60.1892	45.9516	77.4449
5	16931	78.5416	62.1373	97.9488



After defining reliability objectives, the next step for product reliability analysis is to identify key risks.

Technique 2: Identify and Assess Key Reliability Risks

With reliability requirements come changes to the product, materials, components and/or manufacturing process. Next, we want to ensure that we identify and assess key risks that may result from these updates.

You can estimate reliability risks by verifying any of the critical checkpoints below:

- Failure modes of all functions (failed hardware or software, failed interface, degradation of materials, etc.) Failure mode is defined as the way a component, (sub)system could fail to meet the design intent and customer requirements.
- Warranty data from prior designs
- Component or material change
- Whether new application of existing components adds stress and risks
- Industry expert collateral/materials
- Whether shelf life will be a realistic target for the new design
- Supplier analysis on materials and components
- Degradation estimate

To demonstrate one of the checkpoints, we highlight how an engineer assesses the reliability of a redesigned compressor case for jet engines with the help of Minitab® Statistical Software.

Example: Regression with Life Data[3]

Overview: To test the design, engineers use a machine to throw a single projectile into each compressor case. After the projectile impact, engineers inspect the compressor for failure every twelve hours.

The engineers perform regression with life data analysis to evaluate the relationship between case design, the projectile weight, and the failure time. They also want to estimate the failure times at which they can expect 1% and 5% of the engines to fail. The engineers use a Weibull distribution to model the data.

Reliability Tool Used: Regression with Life Data

Results: In the regression table, the p-values for design and weight are significant at an α-level of 0.05. Therefore, the engineers conclude that both the case design and the projectile weight have a statistically significant effect on the failure times. The coefficients for the predictors can be used to define an equation that describes the relationship between the case design, the projectile weight, and the failure time for the engines.

The table of percentiles shows the 1st and 5th percentiles for each combination of case design and projectile weight. The time that passes before 1% or 5% of the engines fail is longer for the new case design than the standard case design, at all the projectile weights. For example, after being subject to a 10-pound projectile, 1% of the engines with a standard case design can be expected to fail after approximately 101.663 hours. With the new case design, 1% of the engines can be expected to fail after approximately 205.882 hours.

The engineers can say with confidence that the reliability of the redesigned compressor case of jet engines is better than the old one.

Censoring

Censoring Information	Count
Right censored value	25
Interval censored value	23

Estimation Method: Maximum Likelihood

Distribution: Weibull

Relationship with accelerating variable(s): Linear

Regression Table

		Standard			95.0% Normal CI	
Predictor	Coef	Error	Z	P	Lower	Upper
Intercept	6.68731	0.193766	34.51	0.000	6.30754	7.06709
Design						
Standard	-0.705643	0.0725597	-9.72	0.000	-0.847857	-0.563428
Weight	-0.0565899	0.0212396	-2.66	0.008	-0.0982187	-0.0149611
Shape	5.79286	1.07980			4.02001	8.34755

Log-Likelihood = -88.282

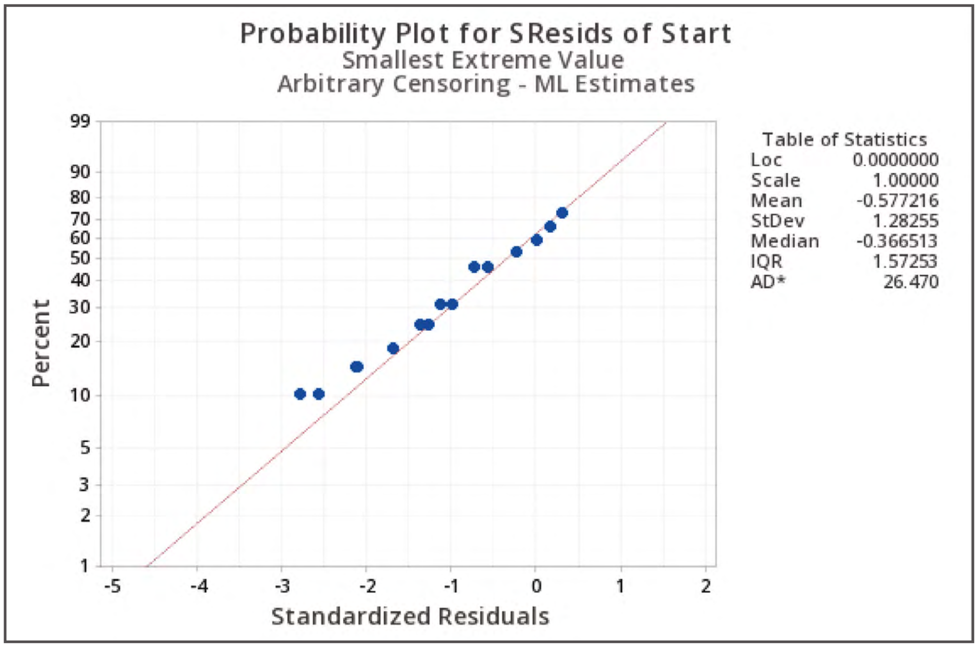
Anderson-Darling (adjusted) Goodness-of-Fit

Standardized Residuals = 26.470

Table of Percentiles

				Standard	95.0% Normal CI	
Percent	Design	Weight	Percentile	Error	Lower	Upper
1	Standard	5.0	134.911	17.6574	104.385	174.363
1	Standard	7.5	117.113	16.0279	89.5591	153.144
1	Standard	10.0	101.663	16.3830	74.1295	139.423
1	New	5.0	273.214	36.8022	209.819	355.763
1	New	7.5	237.171	32.6878	181.028	310.726
1	New	10.0	205.882	32.8675	150.568	281.518
5	Standard	5.0	178.749	16.9676	148.404	215.300
5	Standard	7.5	155.168	14.1107	129.836	185.443
5	Standard	10.0	134.698	15.4568	107.568	168.670
5	New	5.0	361.994	36.0778	297.761	440.084
5	New	7.5	314.239	28.8741	262.450	376.247
5	New	10.0	272.783	30.6102	218.928	339.887

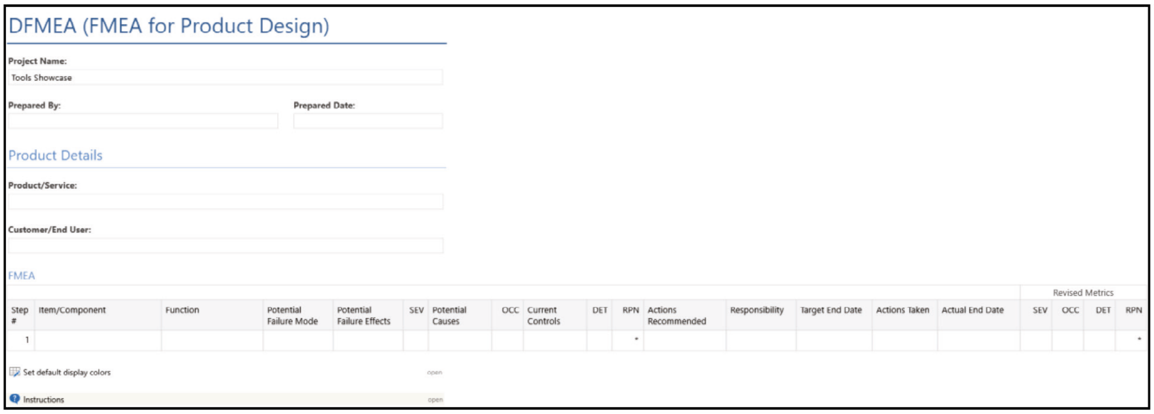
The probability plot of the standardized residuals shows that the points follow an approximate straight line. Therefore, it can be assumed that the model is appropriate.



In addition to Minitab® Statistical Software, Minitab offers another solution to support your product design needs for reliability. Minitab Workspace® enables you to move work forward with powerful visual tools, brainstorming diagrams and forms all in one intuitive interface.

Design Failure Modes and Effects Analysis (DFMEA) is one of those tools, used to identify failure modes and considers all the requirements, customer usage and operating conditions of a product or process. The output can inform Physics of Failure (aging, possible damages), System Analysis, Reliability Prediction, Life Testing and Accelerated Life Testing and Packaging (storage, environmental conditions in store, manipulations, or unintended use from purchase to consumption).

Together, these Minitab solutions can efficiently address your reliability needs.



After assessing key reliability risks, we want to evaluate baseline reliability.

Technique 3: Estimate Baseline Reliability

Estimating baseline reliability will help us focus the reliability analysis to be run, identify the necessary failure prevention, and determine possible costs and gains.

Goals for this technique:

- Verification (or validation) of meeting the requirements
- Improving the understanding of the product, process, failure modes and mechanisms
- Identifying shortages (deficiencies)
- Detecting areas for design improvement

The reliability of a product results from the reliability of its subsystems, components, and materials:

system reliability = f(component reliability)

In order to implement this technique, there must be a clear understanding established about the system and its functions, usage conditions and requirements.

We could compute the baseline reliability of subsystems and components based on field data (if reliable and traceable), or knowledge on physics of failure, reliability predictions documented for similar products, simulation models, warranty and test data from comparable subsystems and components.

To successfully accomplish your baseline reliability evaluation, we recommend any of the following tools found in Minitab® Statistical Software:

- Test Plans
- Repairable System Analysis
- Regression with Life Data
- Probit Analysis

In the example to follow, we illustrate the use of an Estimation Test Plan to develop a new type of insulation.

Example: Estimation Test Plan[4]

Overview: Engineers want to determine the sample sizes necessary to estimate the 10th percentile when the distance from the lower bound to the estimate is within 100, 200, or 300 hours. The engineers will perform reliability tests on small specimens for 1000 hours. They use the following information for the test plan:

- Approximately 12% of the specimens are expected to fail in the first 500 hours of the test.
- Approximately 20% of the specimens are expected to fail by the end of 1000 hours.
- The failure times for the insulation follow a Weibull distribution.

Type I right-censored data (Single Censoring)

Estimated parameter: 10th percentile
Calculated planning estimate = 393.094
Target Confidence Level = 95%
Precision in terms of a one-sided confidence interval that gives a lower bound for the parameter.

Planning Values
Percentile values 500, 1000 for percents 12, 20

Planning Distribution

Distribution	Scale	Shape
Weibull	6464.18	0.803708

Test Plans

Censoring Time	Precision	Sample Size	Actual Confidence Level
1000	100	354	95.0011
1000	200	61	95.0892
1000	300	15	95.1695

Reliability Tool Used: Estimation Test Plan

Results: To calculate the sample sizes, Minitab uses a Weibull distribution with a scale of 6464.18 and a shape of 0.8037. With a censoring time of 1000, hours and a target confidence level of 95% for a one-sided confidence interval, the calculated sample sizes for each precision value are as follows:

- 354 units must be tested to estimate a lower bound for the 10th percentile within 100 hours.
- 61 units must be tested to estimate a lower bound for the 10th percentile within 200 hours.
- 15 units must be tested to estimate a lower bound for the 10th percentile within 300 hours.

Use an Estimation Test Plan to determine the number of test units that you need to estimate percentiles or reliability values with a specified degree of precision.

An estimation test plan can be used to answer questions such as:

- How many units should be tested to estimate the 10th percentile with a 95% lower confidence bound within 100 hours of the estimate?
- How many cables does an engineer need to test until failure to predict the survival probability of the cables at a force of 5000 pounds?

Now that we know how to estimate our baseline reliability, we need to validate the actual reliability of our product and improve it.

Technique 4: Validate and Improve Reliability

In this step, multiple components or subsystems are being acquired or built, and prototypes are being assembled. Most of the 'traditional' testing and analysis takes place during this phase, including continuous sampling of components and subsystems acquired from suppliers for Accelerated Life Testing and Regression with Life Data in Minitab.

When reaching the manufacturing stage, DfR efforts should focus primarily on reducing or eliminating problems that could occur during the manufacturing process. Manufacturing introduces variations in any of the following: material, processes, manufacturing sites, human operators, and contamination. The product's reliability should be re-evaluated considering these additional variables. To improve robustness, design modifications might be necessary.

Critical checkpoints to successfully implement this step:

- Verification (or validation) that requirements are being met, based on experiments planned and run in a structured way as determined by Design of Experience (DOE) techniques
- Improving understanding of the product and process
- Understanding the effect (and interactions) of critical use, design, and environmental parameters as determined by an analysis of the results of the experimental runs
- Identification of shortages (deficiencies) and areas for design improvement
- Reliability test on products from semi-industrial line

Let's look at an example, where we use the Accelerated Life Testing to model product performance at extreme stress levels and extrapolate the results back to normal-use conditions.

Example: Accelerated Life Testing[5]

Overview: A reliability engineer wants to investigate electrical current leakage between transistors in an electronic device. When current leakage reaches a certain threshold value, the electronic device fails. To accelerate failures for testing, the devices were tested under much higher-than-normal temperatures, and devices were inspected for failure every two days.

Reliability Tool Used: Accelerated Life Tests

The engineer performs an Accelerated Life Test to estimate the time until failure for the device under normal operating conditions (55° C) and worst-case operating conditions (85° C). The engineer wants to determine the B5 life, which is the estimated amount of time until 5% of the devices are expected to fail.

Response Variable Start: StartTime End: EndTime
Frequency: Count

Censoring

Censoring Information	Count
Right censored value	95
Interval censored value	58

Estimation Method: Maximum Likelihood

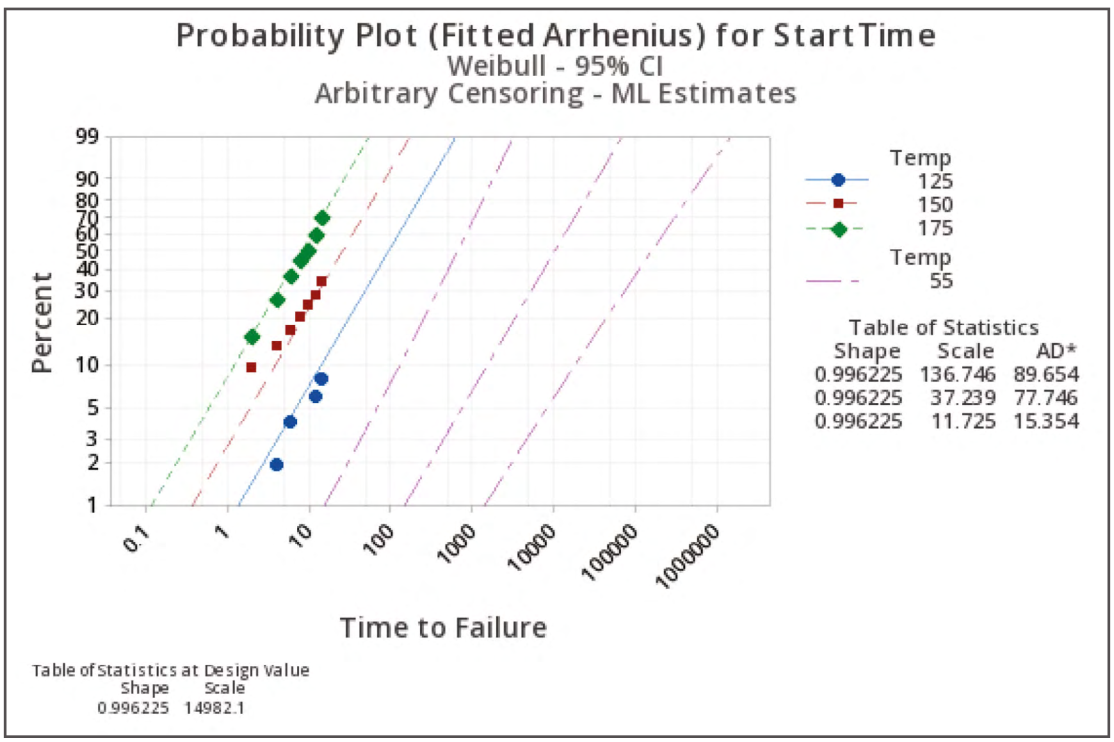
Distribution: Weibull

Relationship with accelerating variable(s): Arrhenius

Regression Table

		Standard			95.0% Normal CI	
Predictor	Coef	Error	Z	P	Lower	Upper
Intercept	-17.0990	4.13633	-4.13	0.000	-25.2061	-8.99195
Temp	0.755405	0.157076	4.81	0.000	0.447542	1.06327
Shape	0.996225	0.136187			0.762071	1.30232

Log-Likelihood = -191.130



The probability plot based on the fitted model can help you determine whether the distribution, transformation, and assumption of equal shape (Weibull) at each level of the accelerating variable are appropriate. For these data, the points follow an approximate straight line. Therefore, assumptions of the model are appropriate for the accelerating variable levels.

Anderson-Darling (adjusted) Goodness-of-Fit

At each accelerating level

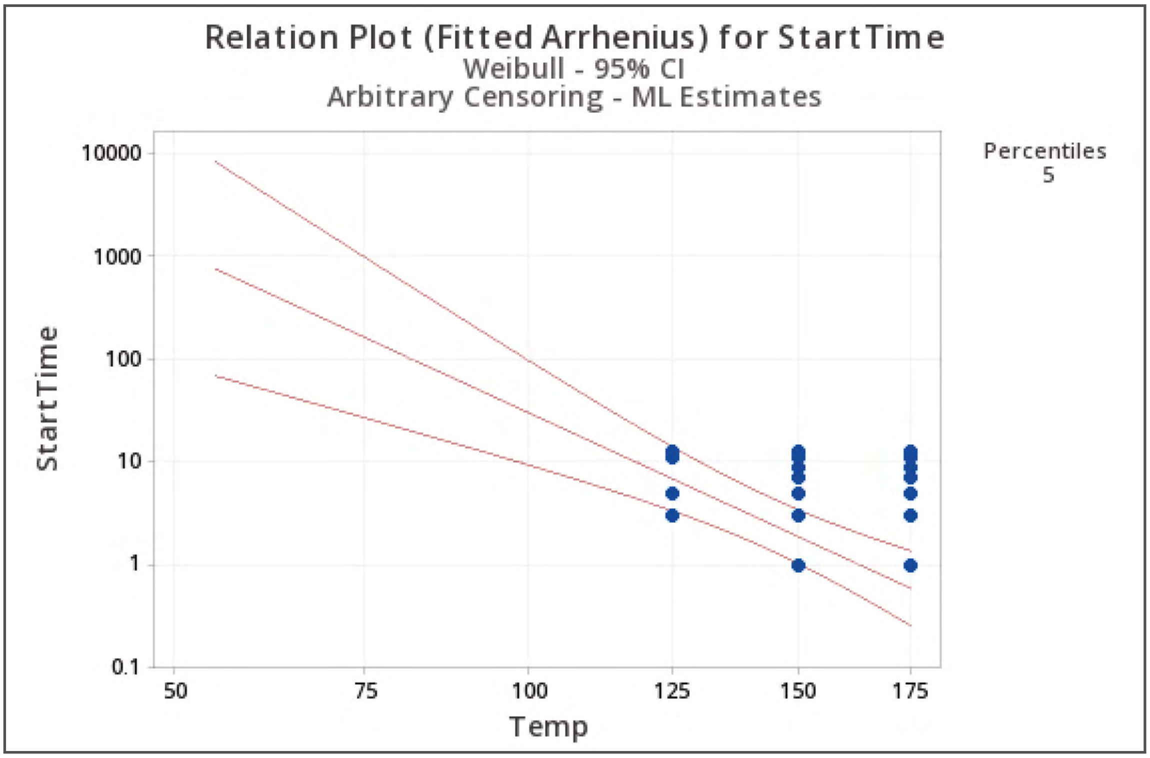
Level	Fitted Model
125	89.654
150	77.746
175	15.354

Table of Percentiles

Percent	Temp	Percentile	Standard Error	95.0% Normal CI Lower	95.0% Normal CI Upper
5	55	759.882	928.717	69.2500	8338.21
5	85	81.0926	63.2317	17.5897	373.855

Results: Based on the results in the table of percentiles, the engineer can conclude the following:

- At the design temperature (55° C), 5% of the devices will fail after approximately 760 days (slightly over 2 years).
- At the worst-case temperature (85° C), 5% of the devices will fail after approximately 81 days.
- These results are also displayed in the relation plot below.

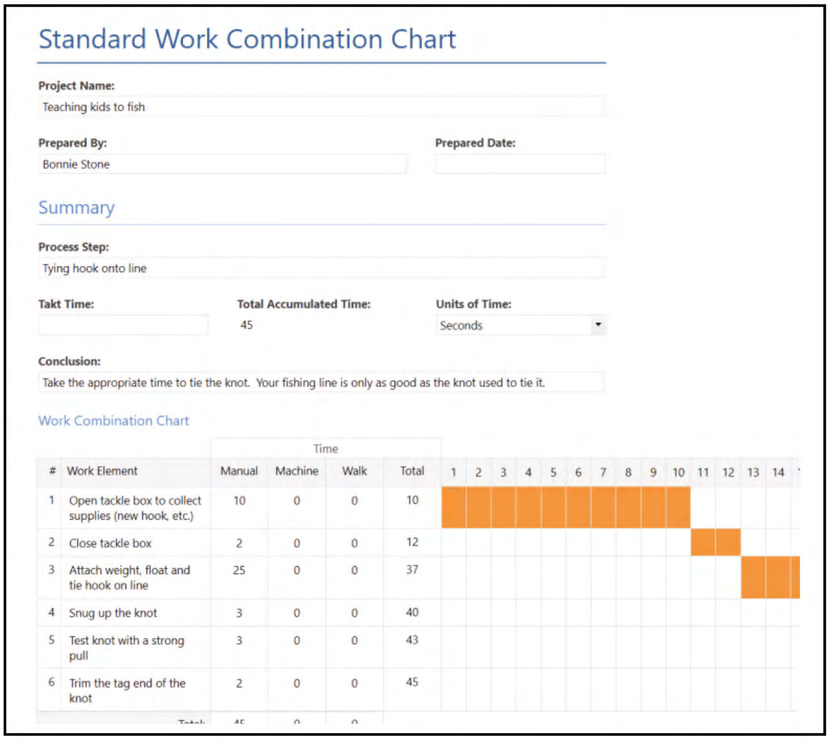


By using a harsher working environment, in this case increased temperature during testing, the engineer was able to quickly obtain life data. The results are induced by fitting a physically reasonable statistical model, to obtain estimates of lifetime or long-term reliability at lower, normal levels of operating conditions or stress.

Now that the product is sent to mass production, the manufacturing and assembly processes could impact its reliability performance, which takes us to our final step: to sustain, monitor and control reliability.

Technique 5: Sustain, Monitor and Control Reliability

To ensure that reliability is controlled and sustained properly, factory audits are essential to avoid any shift in the manufacturing process. Inspections, supplier control, routine tests, storing finished products, Measurement System Analysis and records are monitored accordingly. To create a list of visual inputs and outputs to monitor, a Control Plan template, found in Minitab Workspace, is an ideal solution to execute this technique successfully.



Standard Work Combination Chart

Project Name: Teaching kids to fish

Prepared By: Bonnie Stone

Prepared Date:

Summary

Process Step: Tying hook onto line

Takt Time:

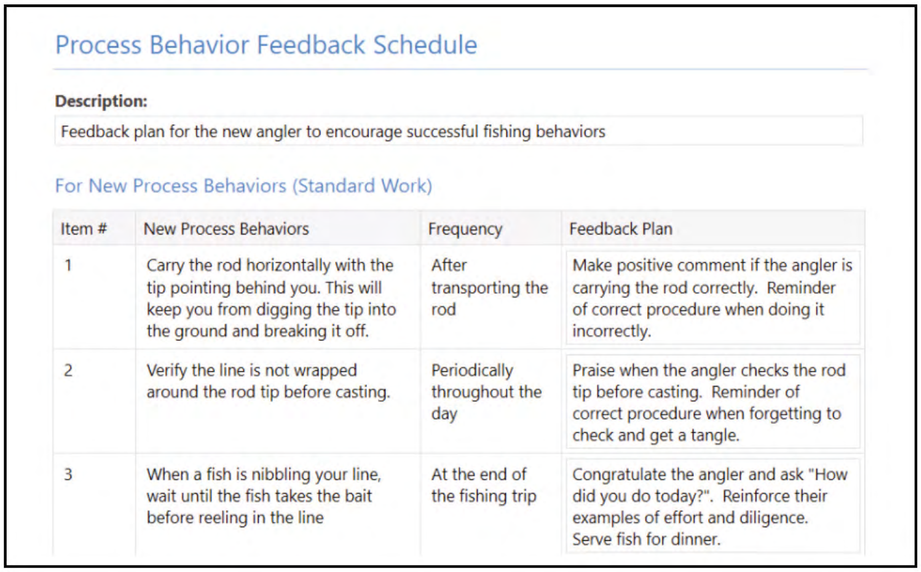
Total Accumulated Time: 45

Units of Time: Seconds

Conclusion: Take the appropriate time to tie the knot. Your fishing line is only as good as the knot used to tie it.

Work Combination Chart

#	Work Element	Manual (Time)	Machine (Time)	Walk (Time)	Total
1	Open tackle box to collect supplies (new hook, etc.)	10	0	0	10
2	Close tackle box	2	0	0	12
3	Attach weight, float and tie hook on line	25	0	0	37
4	Snug up the knot	3	0	0	40
5	Test knot with a strong pull	3	0	0	43
6	Trim the tag end of the knot	2	0	0	45
	Total:	45	0	0	



Process Behavior Feedback Schedule

Description: Feedback plan for the new angler to encourage successful fishing behaviors

For New Process Behaviors (Standard Work)

Item #	New Process Behaviors	Frequency	Feedback Plan
1	Carry the rod horizontally with the tip pointing behind you. This will keep you from digging the tip into the ground and breaking it off.	After transporting the rod	Make positive comment if the angler is carrying the rod correctly. Reminder of correct procedure when doing it incorrectly.
2	Verify the line is not wrapped around the rod tip before casting.	Periodically throughout the day	Praise when the angler checks the rod tip before casting. Reminder of correct procedure when forgetting to check and get a tangle.
3	When a fish is nibbling your line, wait until the fish takes the bait before reeling in the line	At the end of the fishing trip	Congratulate the angler and ask "How did you do today?". Reinforce their examples of effort and diligence. Serve fish for dinner.

Beyond continuous monitoring, field data analysis is necessary to observe the behavior of the product in its operating conditions, to calculate the actual reliability performance.

As you start to get data from the field, you may end up with a reliability data set with no failures, because no product has failed yet. When few or no failures exist, Weibayes analysis is particularly useful to compare a redesigned component to an existing component. We use Bayes analysis to answer questions such as “Has a certain mode of failure been eliminated or improved on a redesigned component?” or “How does the lifetime of the redesigned component compare to the lifetime of the existing component?”

Example: Weibayes Analysis for Data Set Returned from the Field with No Failures

Overview: A thermostat on a diesel engine determines when the oil temperature has risen to the point where the oil must be cooled. The thermostat has been redesigned and engineers want to determine if the redesigned unit has a 5th percentile of at least 421 hours. The demonstration test plan requires six thermostats be placed on test for 1,400 hours each. The failure times of the original thermostat fit a Weibull distribution with $\beta = 1.9$ and $\eta = 2010$.

The first four thermostats passed the 1,400 hour test. The last thermostat failed after 994 hours due to a malfunction of the testing device. The 6th thermostat was successfully tested for 1,806 hours (an additional 406 hours) to “make-up” for lost time. The goal is to determine whether the reliability standard was met using this modified demonstration test.

With no failures, we must specify the shape parameter (Weibull) or the scale parameter (other distributions) in the analysis. This analysis is referred to as a Bayes analysis because you are incorporating prior information in the analysis. In the case of the Weibull model, this technique is more commonly called Weibayes.

Reliability Tool Used: Parametric Distribution Analysis

Results: Examine the 5th percentile in the Table of Percentiles. The lower bound exceeds 421 hours. The reliability standard has been met and the redesigned thermostat has passed the demonstration test.

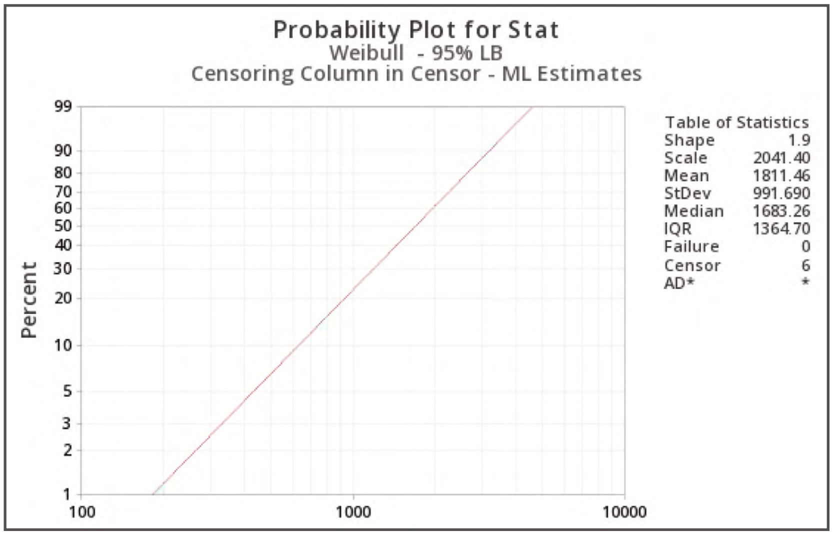
The survival probability at 421 hours is found in the table of survival probabilities. The lower bound exceeds 0.95. The reliability standard has been met and the redesigned thermostat has passed the demonstration test.

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	*	*	181.319	*
2	*	*	261.841	*
3	*	*	325.001	*
4	*	*	379.157	*
5	*	*	427.575	*
6	*	*	471.938	*
7	*	*	513.249	*
8	*	*	552.166	*
9	*	*	589.146	*
10	*	*	624.522	*
20	*	*	926.995	*
30	*	*	1186.54	*
40	*	*	1433.46	*
50	*	*	1683.26	*
60	*	*	1949.60	*
70	*	*	2250.91	*
80	*	*	2622.43	*
90	*	*	3166.41	*
91	*	*	3241.86	*
92	*	*	3324.38	*
93	*	*	3415.75	*
94	*	*	3518.57	*
95	*	*	3636.79	*
96	*	*	3776.94	*
97	*	*	3951.00	*
98	*	*	4185.22	*
99	*	*	4560.42	*

Table of Survival Probabilities

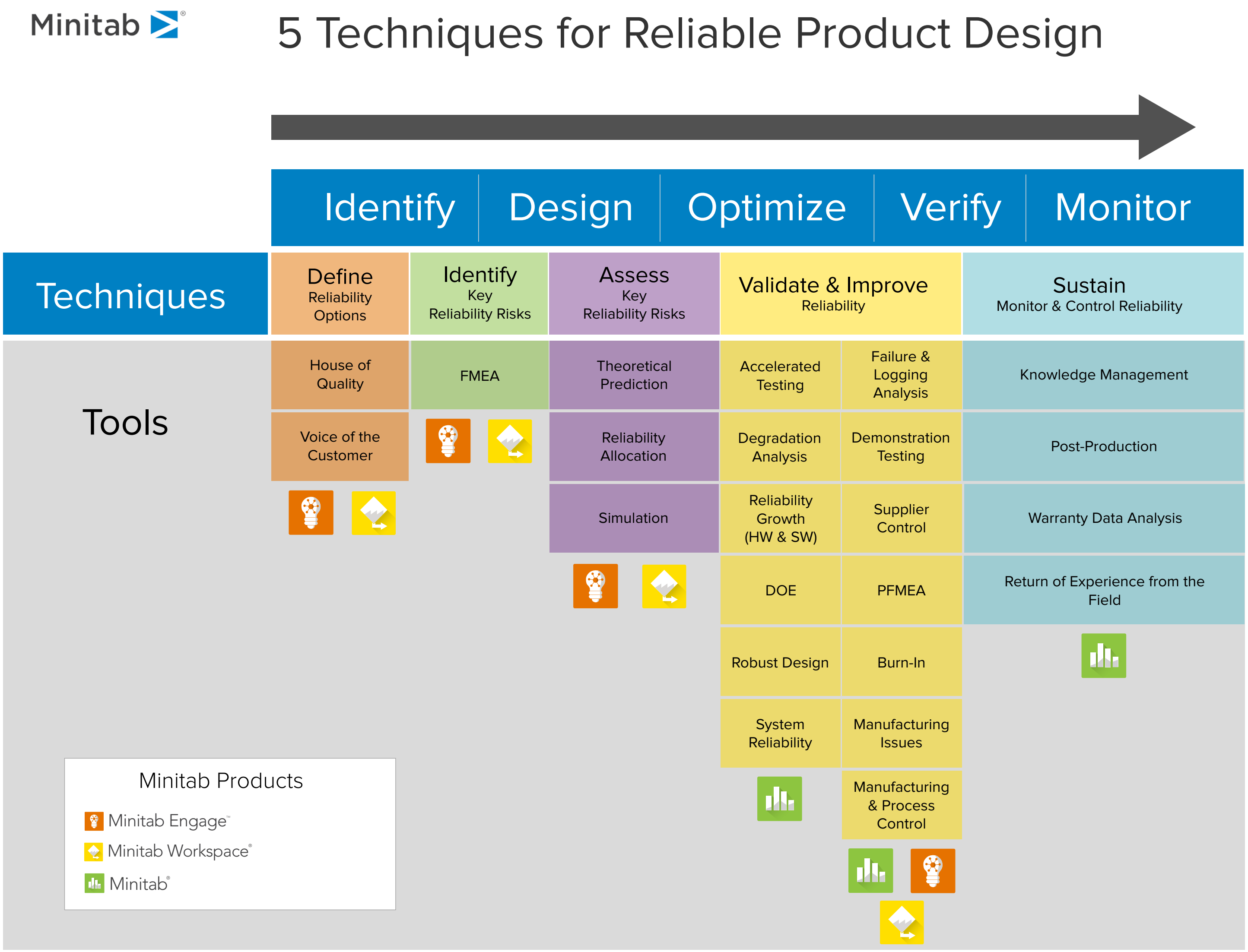
Time	Probability	95.0% Normal CI Lower	Upper
421	*	0.951415	*



Conclusion

The Design for Reliability methodology is the ideal solution for organizations that want to stay competitive in their field, proactively bring a reliable product to the market, and exceed customer satisfaction. Achieving your organization's reliability goals requires a strategic vision, proper planning, sufficient organizational resource allocation and the integration of reliability practices into your development projects.

Minitab Solutions Analytics™, backed by a customer-focused team of experts, can help your organization apply the techniques in the most efficient and operational manner to make the best business decision.



About Minitab

Minitab has spent the past 50 years helping companies and organizations drive cost containment, enhance product and service quality and boost customer satisfaction with our comprehensive, easy-to-use, best-in-class suite of data analysis and process improvement tools. Thousands of businesses and institutions worldwide work with Minitab because of our unique and integrated approach of solutions analytics, empowering you to make better decisions that drive business excellence.

Interested in accessing additional guidance regarding tools and skills to support your reliability initiatives? Contact us to get help from our expert statisticians, consultants and world-class technical support today.

If you are interested in expanding your reliability knowledge, please visit our reliability learning track.

Sources and Additional Materials

White Paper References

1. Berkley Global Product Recall
2. Minitab Example: Warranty Prediction
3. Minitab Example: Regression with Life Data
4. Minitab Example: Estimation Test Plan
5. Minitab Example: Accelerated Life Testing

Minitab Reliability Materials

Blog

- Blog: How to Calculate B10 Life with Minitab Part 1
- Blog: How to Calculate BX Life with Minitab Part 2
- Blog: How to Calculate BX Life with Minitab Part 2b: Handling Triangular Matrix Data
- Blog: Will the Weibull Distribution be on the Demonstration Test?
- Blog: Exponential Distribution
- Blog: Using FMEA to Improve Quality Assurance
- Blog: For Want of an FMEA, the Empire Fell
- Blog: Automotive Industry Guidelines. Apply the AIAG-VDA FMEA Methods with Confidence.

Help Article:

- Critical to reliability CTQs section

On-Demand Webinars

- [Case Study] Time-to-Market and Design for Reliability at the Speed of Light at Signify
- [Case Study] Break habits, not your products: How Signify switched materials and processing without sacrificing reliability

White Paper

- White Paper: When Run to Failure Isn't an Option

Additional Reliability Materials

- Harvard Business Review: A Strategic Approach to Managing Product Recalls
- Delft University of Technology: The Lifetime Prediction of LED Drivers and Lamps

Minitab®

Talk to Minitab

If you wish to assess how these techniques and tools can help to address your specific reliability challenges, please request a conversation with our Experts