APPENDIX J - BEST PRACTICES FOR LIFE DATA ANALYSIS

Figure J.1. Analytical Treatments

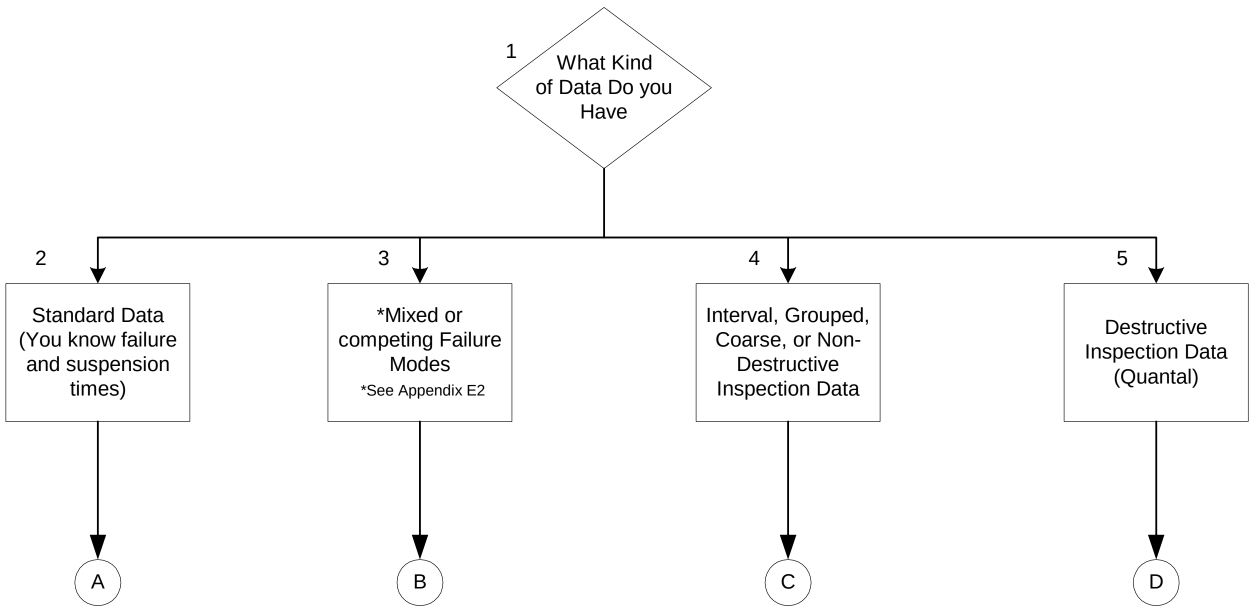


Figure J.2 . The Standard Data Path

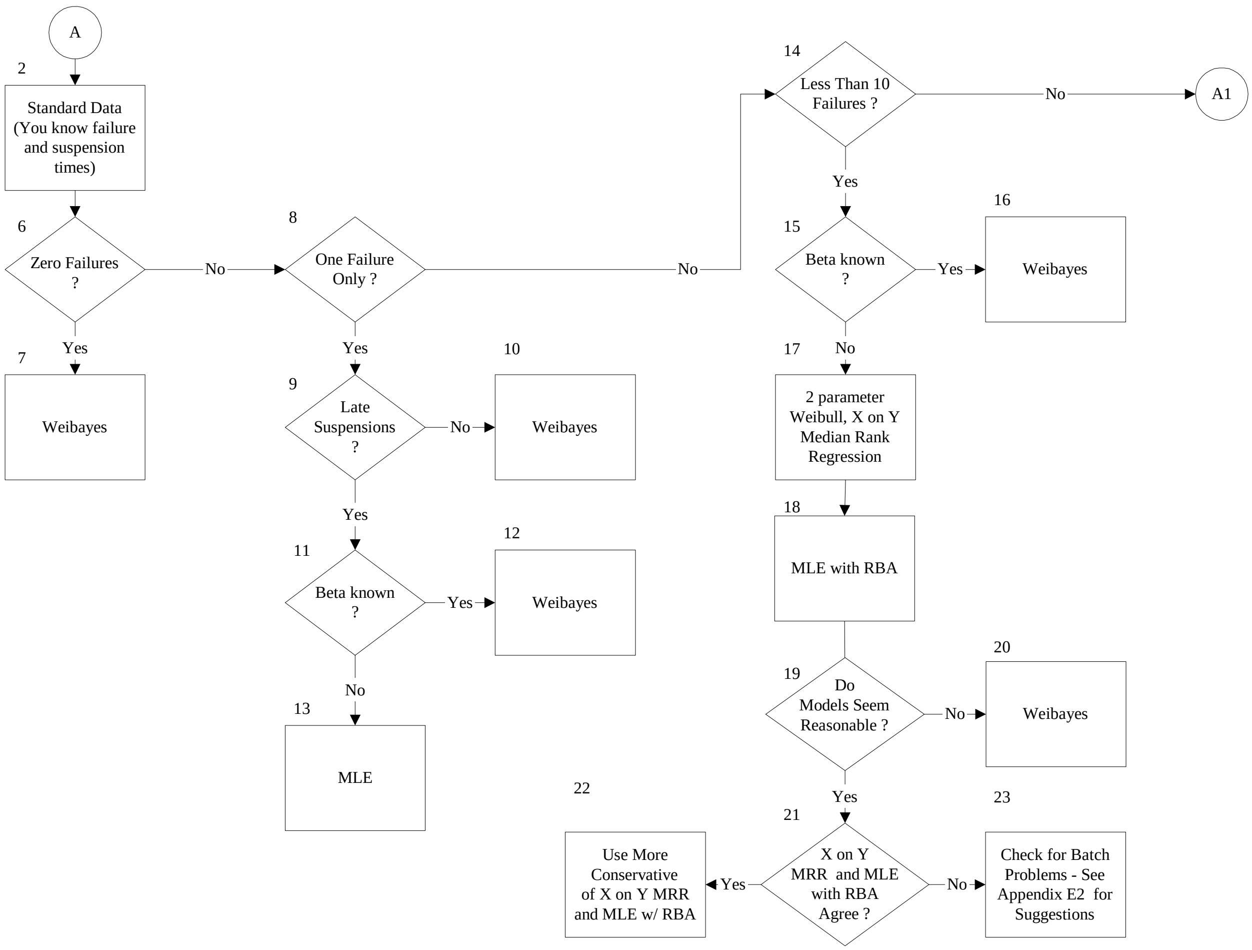


Figure J.2 cont. The Standard Data Path (continued)

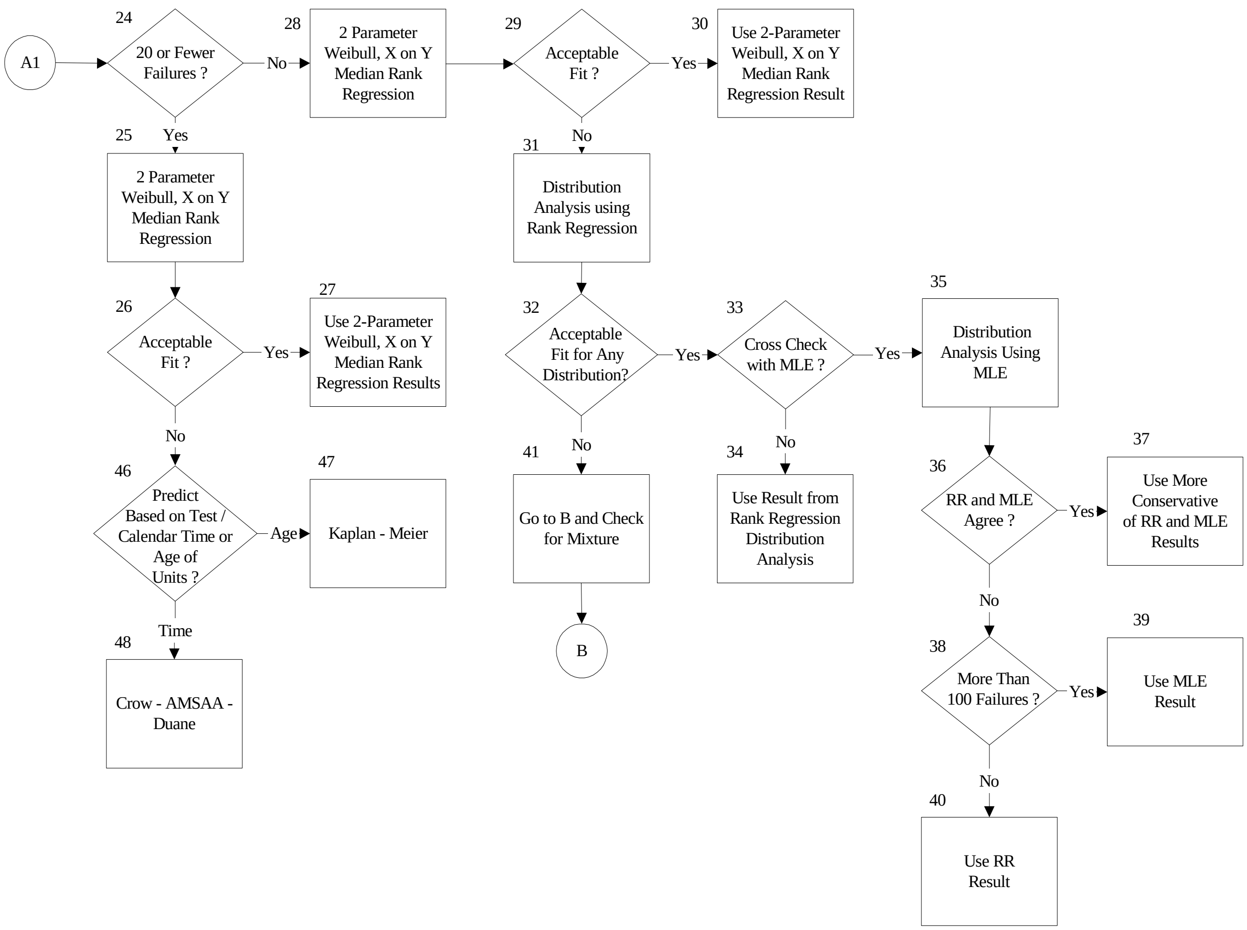
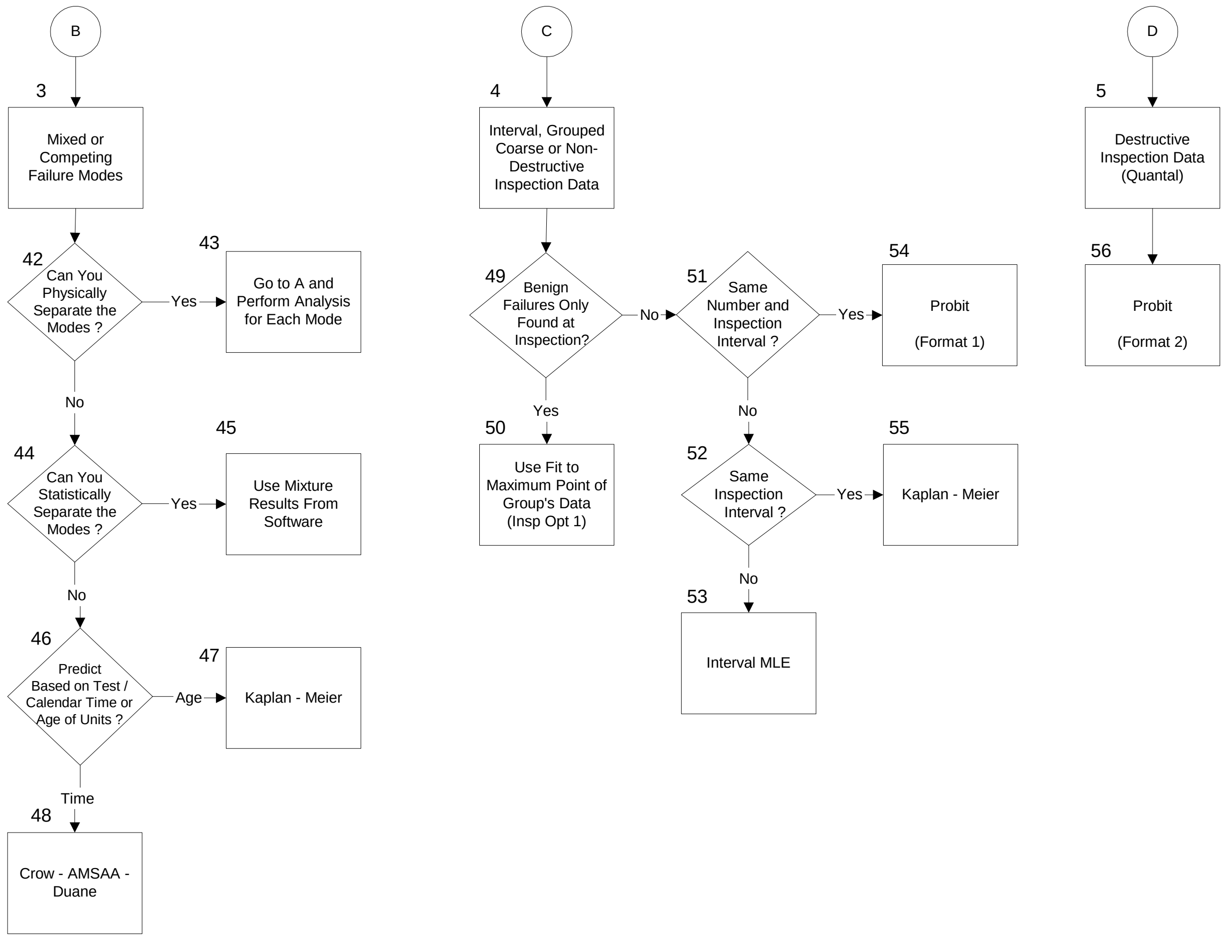


Figure J.3. The remaining analytical treatments



Key to Best Practices for Life Data Analysis Flowchart

> **Note:** This key does not represent a sequential flow of steps. You must use the flowchart to follow the logical flow and branching through the choice of analysis techniques. Use the flowchart as the primary document. Refer to this key when you want more detailed discussion of the numbered flowchart items.

Main Branch Starts Here

1.0 **What Kind of Data Do You Have? –** Understanding the data that you have, or are able to get, is the most important first step in finding the best practice for your analysis. Your data most likely can be classified into one of the four data types described in items 2, 3, 4, and 5 below. (For a discussion and diagrams of these data types, see Reference 1 and Reference 2 at the end of this Appendix.)

2.0 **Standard Data –** You have standard data if you know all of your failure times and all of your suspension times. Most controlled test data are of this type because you know how long each sample has run and whether it has failed or survived. Warranty data may also fall into this group if you know all failure times and are able to make a good estimate of your suspension times. (Go to Branch A.)

3.0 **Mixed or Competing Failure Modes –** (* You usually do not know you have this type of data until you see evidence of it from plots and preliminary analysis. Therefore, start with the analysis for "Standard Data" and allow the flowchart to guide you to this section as necessary.) These data may have multiple failure modes included. You know failure and suspension times, but you do not know if all the failures are the same mode. Warranty data may fall into this group if your claims show that failures have occurred but modes of failure are not known. (Go to Branch B.)

4.0 **Interval, Grouped, Coarse, or Non-Destructive Inspection Data –** These are data where inspections are made at multiple times and the failures are found only at these inspections. The exact failure time is not known – only the interval in which the failure occurred is known. Warranty data can fall into this category if they are handled in monthly counts of failures without exact failure and suspension times. (Go to Branch C.)

5.0 **Destructive Inspection or Quantal Data –** These are data where each piece is inspected only once. You know only that a component failed when inspected or that failure would have occurred after the inspection. Each observation is either censored or failed. Testing of bombs and missiles produces this type of data. When tested, the missile either works or does not work. (Go to Branch D.)

Branch A Starts Here

6.0 Do you have zero failures in your data?

7.0 When you have no failures, the only analysis you can do is Weibayes. You must know the number of units you have and how long they have run. You must make a slope assumption to use Weibayes. You can choose a slope based on previous experience with expected failure modes, on data in your Weibull library, or on knowledge based on the physics of failure. This approach is often used for zero failure testing to see if a known mode of failure has been eliminated.

8.0 Do you have exactly one failure?

9.0 Do you have late suspensions? Late suspensions are units that have not failed and that have already run longer than the failed units.

10.0 If you have one failure and no late suspensions, use Weibayes. You must know the number of units you have and how long they have run. You must make a slope assumption to use Weibayes. You can choose a slope based on previous experience with expected failure modes, on data in your Weibull library, or on knowledge based on the physics of failure.

11.0 If you have late suspensions, do you have a good knowledge of the slope?

12.0 If you feel confident about your knowledge of the slope, use the Weibayes as described in item 10 above. You must make a slope assumption to use Weibayes. You can choose a slope based on previous experience with expected failure modes, on data from your Weibull library, or on knowledge based on the physics of failure.

13.0 If you do not feel confident about your knowledge of the slope, use MLE.

14.0 Do you have more than one failure but fewer than ten failures?

15.0 If you have between two and nine failures, do you have a good knowledge of the slope? A good knowledge of the slope could be knowledge based on previous experience with expected failure modes, on data from your Weibull library, or on the physics of failure.

16.0 If you are satisfied with your knowledge of the slope based on previous experience with expected failure modes, on data from your Weibull library or on knowledge based on the physics of failure, you can use Weibayes.

17.0 If you are not satisfied with your knowledge of the slope, fit a 2-parameter Weibull with X on Y median rank regression.

18.0 Fit a Maximum Likelihood Estimate (MLE) model using the Reduced Bias Adjustment (RBA).

19.0 Do the models fit in 17 and 18 seem reasonable based on your knowledge of the failures?

20.0 If the models in 19 do not seem reasonable, use Weibayes with a slope based on your previous experience with expected failure modes, on data from your Weibull library, or on knowledge based on the physics of failure.

21.0 Are the models in 17 and 18 in reasonable agreement?

22.0 If the models in 17 and 18 are in reasonable agreement, use the more conservative of the two models.
23.0 If the models in 17 and 18 are not in reasonable agreement, consider the possibility of batch problems. There are several indicators to look for:

1) Is the lower confidence bound for present risk above the number of observed failures?
2) Is the MLE slope less than the Median Rank Regression slope?
3) Does the Aggregated Cumulative Hazard indicate a batch effect?

Branch A1 Starts Here

24.0 Do you have between 10 and 20 failures?
25.0 If you have between 10 and 20 failures, fit a 2-parameter Weibull with X on Y median rank regression.

26.0 Is the fit acceptable for the 2-parameter Weibull with X on Y median rank regression? Consider the Critical Correlation Coefficient and the Critical Coefficient of Determination. (See section 3.2.1 in Reference 1.)
27.0 If the fit is acceptable, use the 2-parameter Weibull with X on Y median rank regression.
28.0 Fit a 2-parameter Weibull with X on Y median rank regression.

29.0 Is the fit acceptable for the 2-parameter Weibull with X on Y median rank regression? Consider the Critical Correlation Coefficient and the Critical Coefficient of Determination. (See section 3.2.1 in (Reference 1.)
30.0 Use the results from the 2-parameter Weibull with X on Y median rank regression.
31.0 You have more than 20 failures. Perform a distribution analysis to check for an appropriate distribution.

32.0 Do you have an acceptable fit for any distribution? Consider the Critical Correlation Coefficient and the Critical Coefficient of Determination. (See section 3.2.1 in Reference 1.)

33.0 Do you want to cross-check your rank regression result with MLE?
34.0 Use the rank regression result found in 32.
35.0 Fit MLE model for the best distribution found in 32.

36.0 Do the rank regression and MLE results agree?
37.0 If the rank regression and MLE results agree, use the more conservative of the two models.
38.0 If the rank regression and MLE results do not agree, do you have more than 100 failures?
39.0 If you have more than 100 failures, use the MLE results.
40.0 If you have fewer than 100 failures, use the rank regression result.
41.0 If the fit is not acceptable, check for mixture of failure modes.

Branch B Starts Here

42.0 Can you physically separate the failure modes in the mixture? This requires failure analysis to be performed on the failed parts.
43.0 If you are able to physically separate the failure modes, go to item 2 and perform the analysis for each of the modes of failure. In the analysis, treat failures of other modes as suspension.

44.0 Can you statistically separate the failure modes?
45.0 If you are able to statistically separate the failure modes, use these results and go to item 2 and perform the analysis for each of the modes of failure. In the analysis, treat failures of other modes as suspension.
46.0 If you cannot separate the failure modes, do you want your life prediction to be based on test/calendar time or age of units?

> **Note:** Methods 47 and 48 are particularly useful for warranty data because warranty data often suffer from mixtures.

47.0 If you want to predict life based on the age of the units, use Kaplan-Meier.
48.0 If you want to predict life based on test or calendar time, use Crow-AMSAA-Duane.

Branch C Starts Here

49.0 Do you have benign failures that are found only at inspection?
50.0 When you have benign failures found only at inspection, fit a model to the maximum point of the interval's data. (See Inspection Option 1 in Reference 1.)

51.0 Do you inspect the same number of units and use the same inspection interval for all inspections?
52.0 If you do not inspect the same number at each inspection, do you use the same inspection interval for all inspections?
53.0 If you do not use the same inspection interval, use the interval MLE method.
54.0 If you do use the same inspection interval, use Probit (Format 1).
55.0 If you do use the same number at each inspection and use the same inspection interval for all inspections, use Kaplan-Meier.

Branch D Starts Here

56.0 If you have Destruction Data or Quantal, use Probit (Format 2).

References

Abernethy, R. B. *The New Weibull Handbook*, 3rd edition. 1998.

Nelson, W. *Applied Life Data Analysis*. Wiley & Sons, 1982.