WARRANTY TREND ANALYSIS

The cumulative frequency trend chart is used for 'dynamic' processes where the characteristic of interest occurs over time, such as with field failures/warranty.

The cumulative frequency chart is built with the x-axis representing elapsed time periods since the ‘start’ - weeks or months are typical. The Y-axis is then the *cumulative* fraction of events that occurred in each elapsed time period since the starting time period. The cumulative frequency chart plots a single line that represents the cumulative occurrence rate of all of the parts produced in the starting time period.

The numerator of the fraction is the cumulative count of events that occurred to date. In the case of warranty it is the cumulative number of claims that are received.

The denominator is the total number of claims that are possible, *i.e.* the number of units available to fail. This can be an estimate based on:

The number of parts produced
The number of parts shipped.
The number of parts sold.

If sales are *relatively* close to FIFO, and *relatively* stable, then cumulative sales of that period’s production is preferred. However, this does require knowing when the sold items were produced (possible for some industries – automobiles; not for others – small appliances).

If sales cannot be traced to period of production, then use shipments or total produced as the denominator. When using sales, the denominator grows with elapsed time as more of the period’s production is sold. Of course, when using the production quantity, the denominator does not “grow”…The mathematically imposed assumption is that all of the production is available for a failure & subsequent claim. This leads to less instability in the claim rate in the early months of sales (see example 5 for instability) but “depresses” the true claim rate as the denominator is inflated in the early months. This depression in the early months is acceptable, since *this trend chart is intended to be used to detect trends not absolute failure rates.* Even when using cumulative sales as the denominator, the absolute final claim rate is unknown until the “end” – usually one to two years after the production batch is released.

The further the cumulative claims fraction gets from using FIFO stable sales in the denominator, the more variation will be seen in the early time periods and the longer an elapsed time is necessary to be able to make reliable comparisons between time periods.

At this point it’s important to note that we are not calculating a mean time to failure, so exact *usage* times are not usually necessary. We are going to make a simple relative comparison of failure rates between production time periods. Increased accuracy on when a product is produced and sold will allow us to make an estimate of the improvement (or degradation) earlier, but it only increases the *accuracy of the decision* by a small amount. If failures are usage dependent, then alternative means for the X-axis duration unit of measure must be utilized. This type of analysis requires more elapsed time to "collect" a meaningful sample size, but such is the nature of reliability.

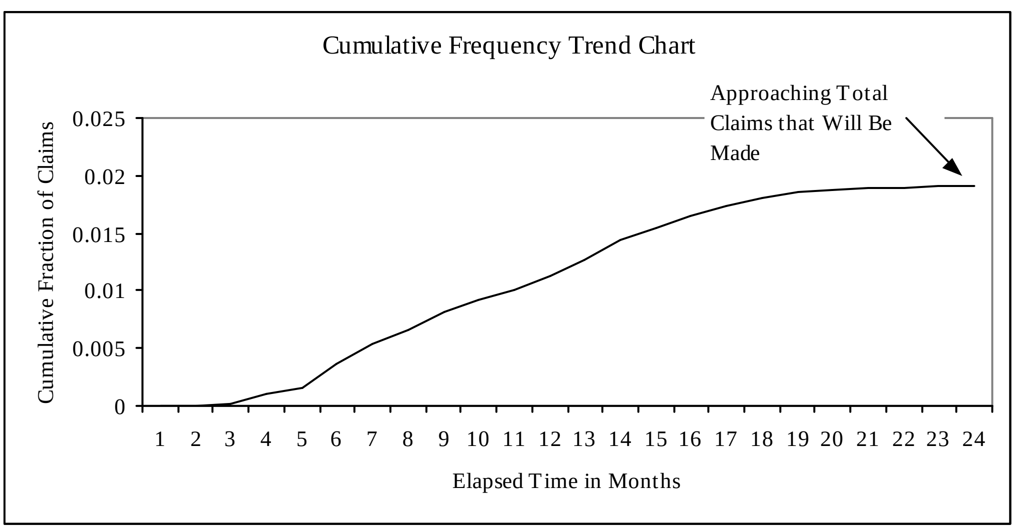
Being a 'little' off on the elapsed time of use due to uncertainty in the difference between date of production and date of actual sale/use won't change the interpretation of the chart, which is based primarily on slope change and ultimate occurrence rates.

If you're off by a 'lot' then you could have trouble with the slopes and you'll need to make some adjustments either in the length of starting period, the definition of your starting period or you may need better data on sales times. The technique is still governed by "garbage in, garbage out". The uncertainty in the data affects how soon you can make comparisons. You have to play with historical data and look at the charts.

EXAMPLE 1: The basic plot

The following example is for a single starting time period of one month's worth of production. The zero point is at the end of the month of production – all product for that month has been produced. *e.g.* if the first month is all product produced in January, the zero point is the end of January and elapsed time point 1 is the end of February. The cumulative frequency is plotted for 24 months after the beginning of the year.

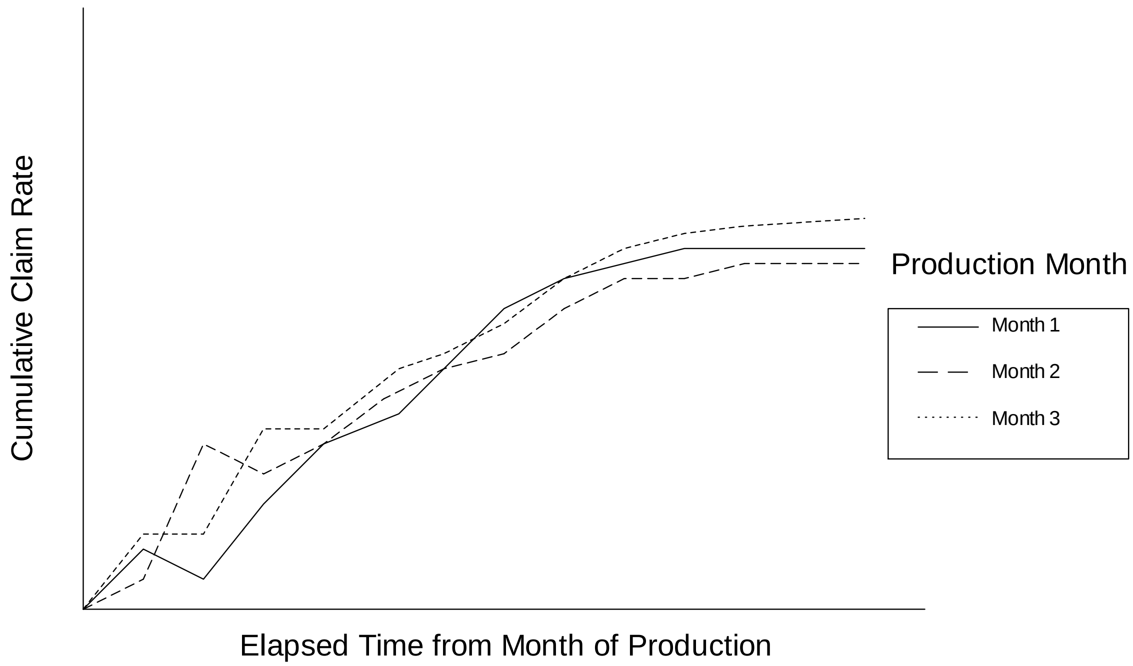
This leads to the following cumulative frequency trend chart:



INTERPRETING THE CHART

EXAMPLE 2: A plot of months that have (statistically/practically) the same claim rate

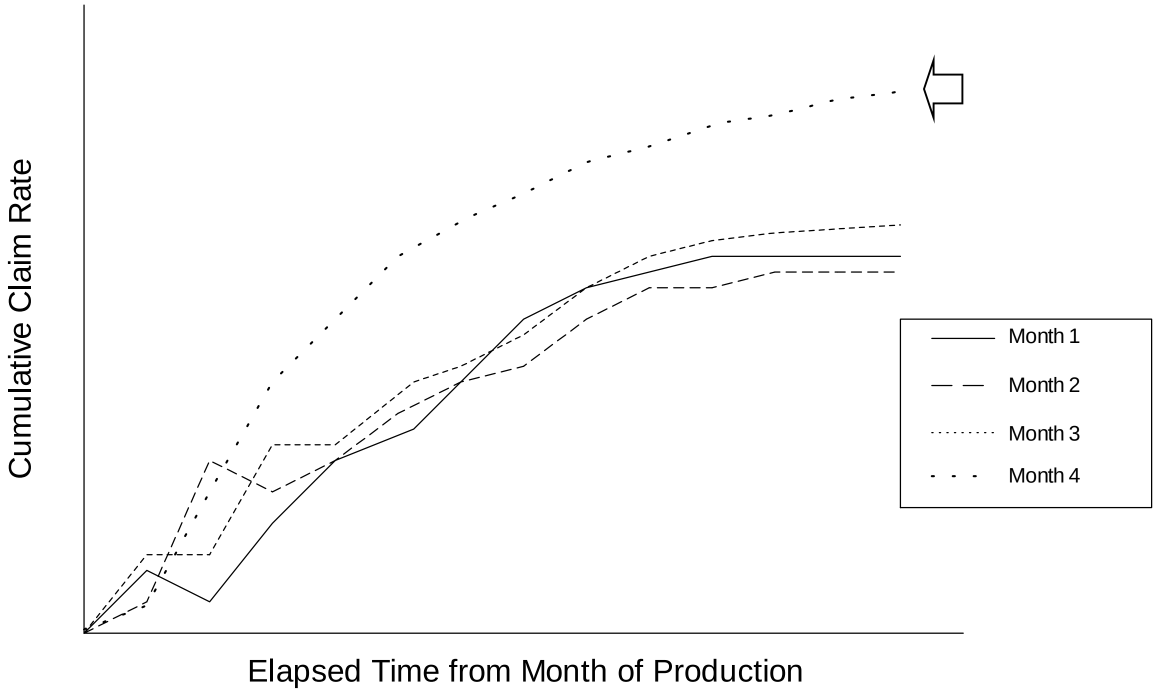
Here is a chart of several months of production plotted together. Note that the cumulative frequency line for each month begins at the zero point on the X axis. This allows for direct comparison of claim rates between production months. **(This is why the X axis is elapsed time and not calendar time)**



Note that the cumulative claim rates for each of the 3 months are very close to each other and are in fact “intertwined”. These 3 months have essentially the same rate.

EXAMPLE 3: A difference between months that represents a degradation in quality.

This chart shows that month 4 is noticeably different - worse - than months 1-3.



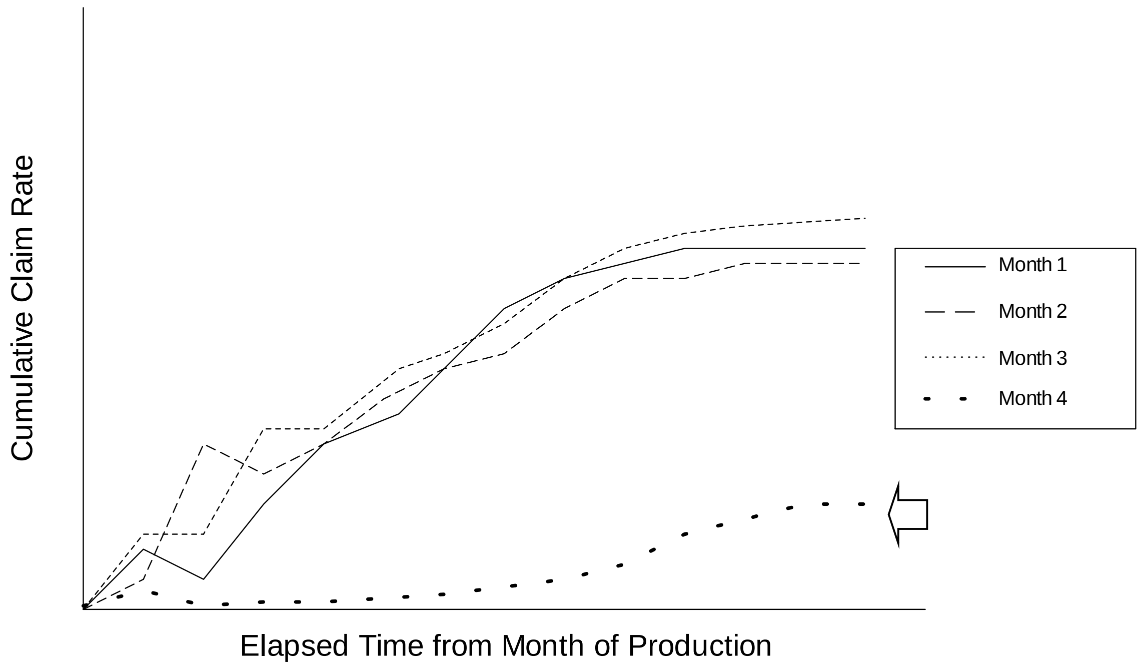
Note that so far we haven't added any statistical limits for the variation. The change is quite obvious from the chart: parts produced in month 4 are definitely worse than parts produced in the first 3 months. Something has changed.

A note on verification & validation is in order at this point. If a change is to be made, or a suspected degradation has occurred it is best to use a small sample verification test to confirm the change quickly. This would consist of two comparison groups: one from the current process and one form the "new" process. There should be an obvious difference in the results of the two groups…a nonparametric test is highly recommended at this point. Since you'll be looking for large changes, power or sensitivity that can be gained in a parametric test, such as the t-test, is not needed and can be harmful, since it will detect small changes that won't help you much.

The validation is then seen in the improvement of the long term warranty results.

EXAMPLE 4: A difference that represents an improvement

Month 4 is clearly better than the first 3 months. If a change was made for month 4 production, it clearly worked.

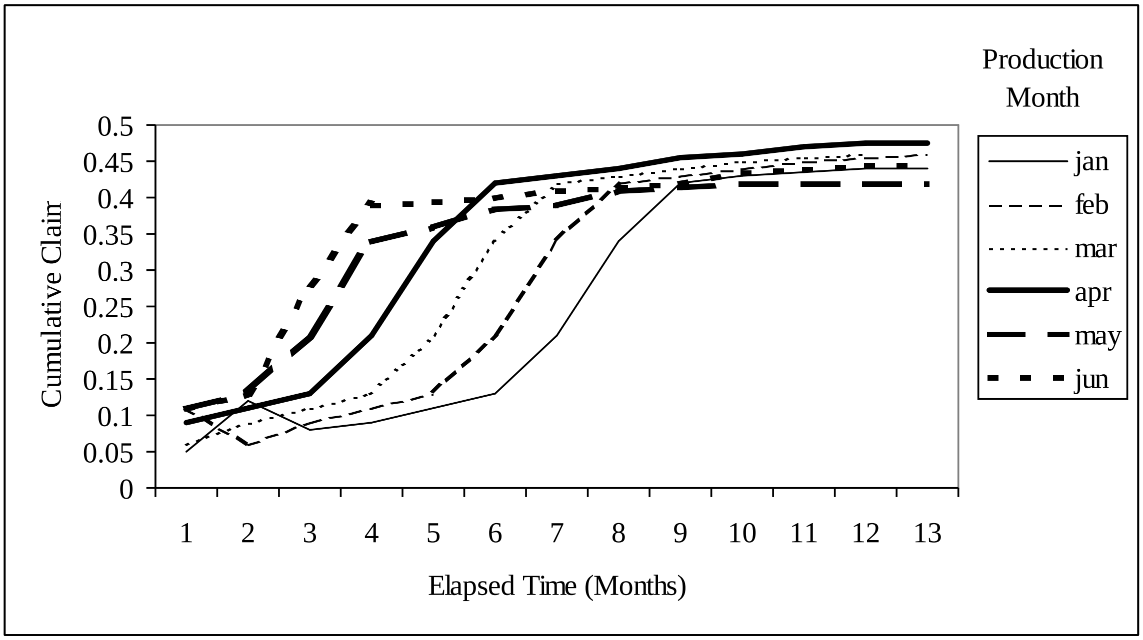


Again note that we do not yet have – or need – statistical control limits…Also note that a fairly accurate decision can be made concerning the existence of an improvement fairly early after the improvement is “released”. It is not necessary to wait until the “end” of the claims for this failure mode. It is necessary to wait until the end to determine to final difference in failure rates.

It is important at this time to acknowledge any given failure mode can have several root causes and the correction of one root cause will not eliminate the failure mode but can significantly reduce it.

EXAMPLE 5: Seasonal failure rates.

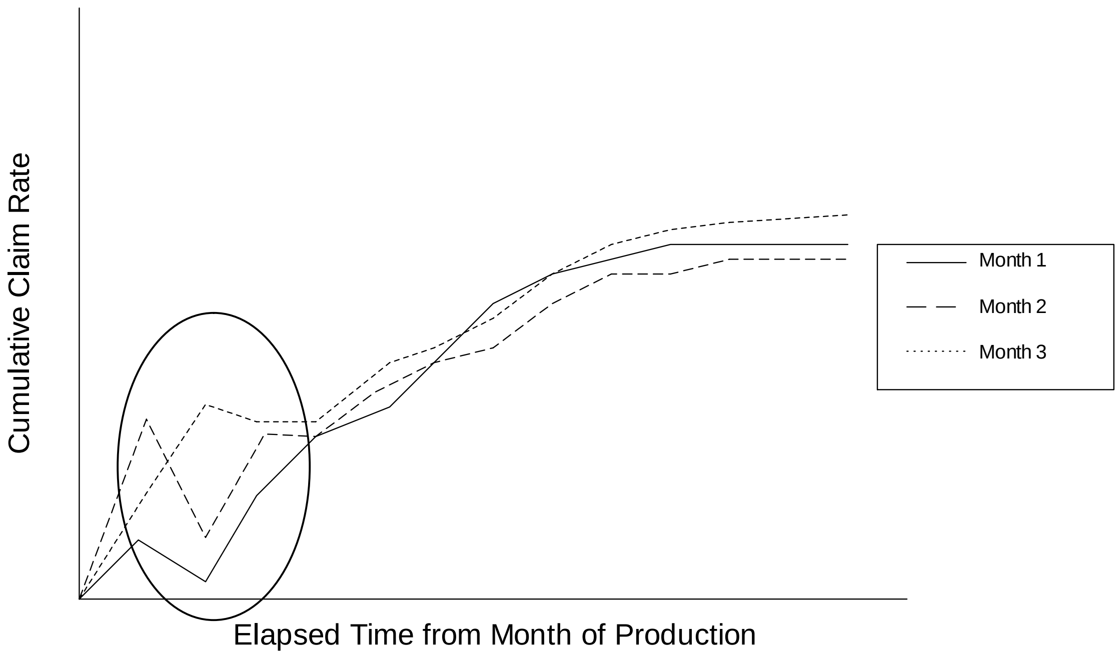
Seasonal effects have a definite "signature" on the cumulative frequency chart. Seasonal effects will be exhibited by staggered "take-off" of the individual production periods' claim frequency (earlier or later failures in elapsed time from the end of the production month…)



The example above has a seasonal effect due to the warmer summer months. Note how the failure rate for each month of production reaches it's maximum level a month earlier as each subsequent month "begins closer to summer…"

EXAMPLE 5: Early Instability.

Most cumulative frequency charts will exhibit some "instability" in the early elapsed time periods; especially if sales are accumulated in the denominator. This instability will make "early" decisions concerning trends very difficult.

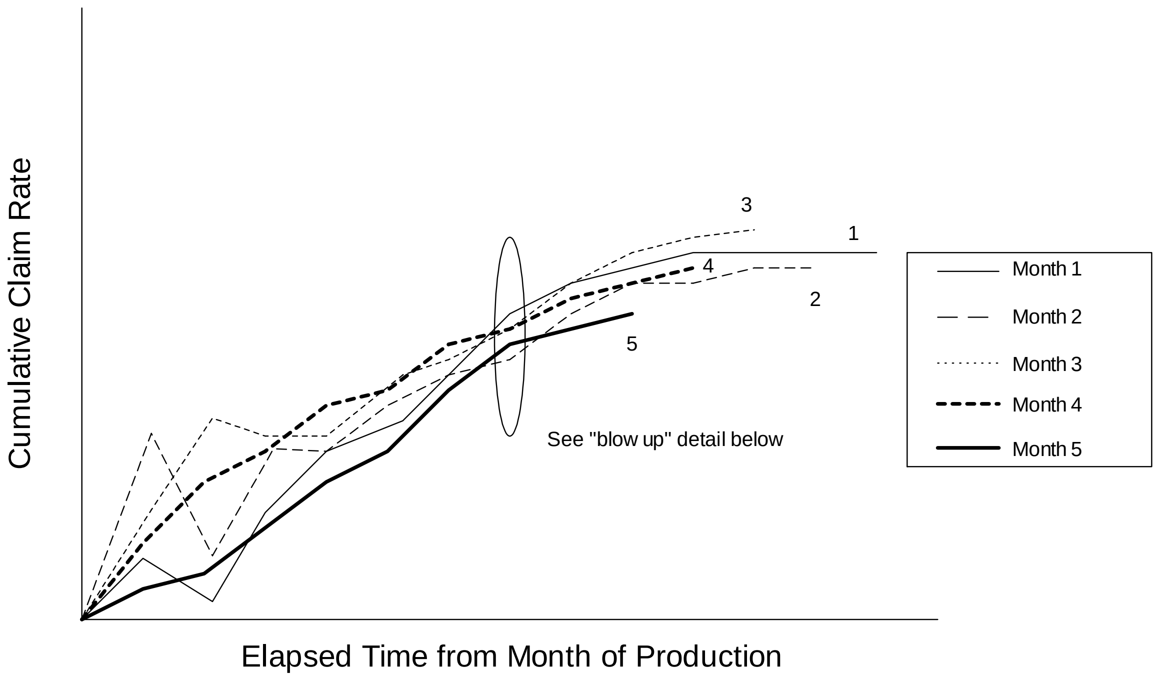


Again, it is necessary to plot historical data and look at the charts to determine when stability is achieved and it is safe to begin making comparisons to look for trends.

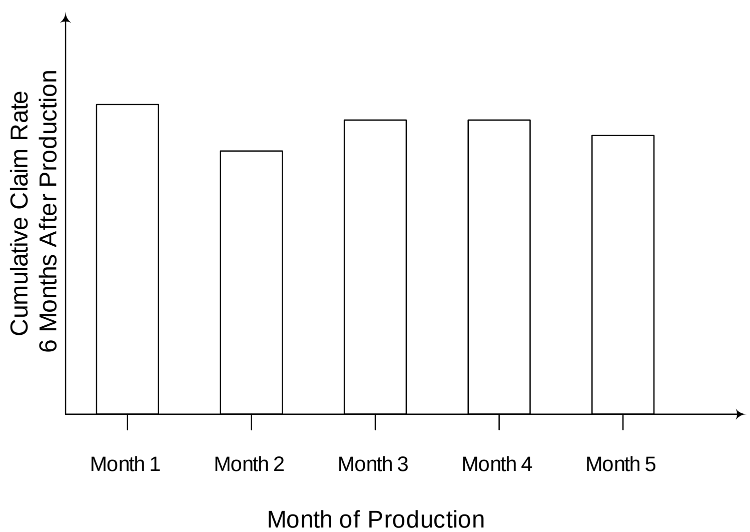
Note that stability and patterns (such as seasonal effects) will differ for each failure mode. It is advised that each failure mode be plotted separately in addition to a chart for the total failure rate for any product…

EXAMPLE 6: Interpreting the chart in "real time".

After the period of stability has been established, month to month comparisons can be made:



The ideal is that people get used to trend data presented in the cumulative trend chart format. This will take some time and some coaching, but will greatly reduce the chart generation time and will avoid misinterpretations and misunderstandings about how the data really "works".



It is highly advised that the above detailed point value chart be used only when necessary (in the transition/learning phases?) and with caution. It is simple to apply "statistical" tests on the data as shown above. Chi-square, Poisson or other attribute type tests may be used with caution. A strong caution: statistical tests on a single elapsed time period "sampled" as shown should be interpreted with great care and always in context of the total dynamic accumulation trend… Variation in the results at any elapsed time point can be influenced by many factors other than a real physical change in the quality of the product. This makes statistical tests harder to apply & interpret properly. Examples of other sources of variation are usage rates during the year, changes in sales rates (also known as *injection* rate), warranty claim responsiveness or time from failure to making the claim – also known as *lag*, *etc*. Important (true) changes for the better or worse will be obvious from the cumulative frequency chart and statistical tests are therefore usually unnecessary.

Technometrics published three articles on appropriate statistical tests for this type of chart. However, while the theory is interesting and proves the validity of the use of the cumulative frequency chart as shown, it is probably more sophisticated than necessary for most applications. The visual and statistical interpretation has been empirically tested and proven highly effective at Honda of America Manufacturing. (This research remains unpublished and is the property of Honda of America Manufacturing. Researchers: Beverly Daniels, John Maceo, Brad Wallace)

<u>Technometrics Articles</u>:

Title: Some Simple Robust Methods for the Analysis of Recurrent Events
QICID: 13609
Copyright: 1995, American Statistical Association and ASQC
Author: *Lawless, J.F.; Nadeau, C.;*
Organization: University of Waterloo, Waterloo, Ontario, Canada
Subject: Nonparametric estimation; Point process data; Poisson processes; Regression; Reliability;
Series: *Technometrics, Vol. 37, No. 2, MAY 1995, pp. 158-168*

Abstract: Nelson discussed a method of estimating the cumulative mean function for identically distributed processes of recurrent events. We show that a similar approach can be used with more general models, including regression. The key idea is to use point estimates based on Poisson models and to develop robust variance estimates that are valid more generally. The methods are illustrated on reliability and warranty data.

Title: Confidence Limits for Recurrence Data - Applied to Cost or Number of Product Repairs
QICID: 13608
Copyright: 1995, American Statistical Association and ASQC
Author: *Nelson, Wayne;*
Organization: Schenectady, NY
Subject: Graphical analysis; Multiply censored stochastic processes; Nonparametric estimate and confidence limits; Recurrence data; Reliability analysis of repair data;
Series: *Technometrics, Vol. 37, No. 2, MAY 1995, pp. 147-157*

Abstract: This article presents a plot and new confidence limits for censored recurrence data. They are applied here to data on product repairs. They also apply to sociological, demographic, production, business, disease, and other recurrence data. For concreteness, reliability terminology is used.

Title: Methods for the Analysis and Prediction of Warranty Claims
QICID: 13494

Author: *Kalbfleisch, J.D.; Lawless, J.F.; Robinson, J.A.;*
Organization: University of Waterloo, Waterloo, Ontario Canada N2L 3G1; General Motors Research Laboratories, Warren, MI 48090
Subject: Field reliability; Log-linear Poisson models; Reporting lags; Warranty data;
Series: *Technometrics, Vol. 33, No. 3, AUGUST 1991, pp. 273-285*

Abstract: This article discusses methods whereby reports of warranty claims can be used to estimate the expected number of warranty claims per unit in service as a function of the time in service. These methods provide estimates that are adjusted for delays or lags corresponding to the time from the claim until it is entered into the data base used for analysis. Forecasts of the number and cost of claims on the population of all units in service are also developed, along with standard errors for these forecasts. The methods are based on a log-linear Poisson model for numbers of warranty claims. Both the case of a known distribution of reporting lag and simultaneous estimation of that distribution are considered. The use of residuals for model checking, extension to allow for extra-Poisson variation, and the estimation of warranty costs are also considered.

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