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Impact of Operations on a Series per Reliability Perspective

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Abstract

The Mean Time Between Failure (MTBF) figures are the average of test durations between failure observations formed into a series. They can be seen to suit classical statistical distributions. An equally possible condition is that they are not stationary as a contradiction to the previous statement. In such worse conditions accepting availability of a concealed statistical property, this paper tries to identify the impact of *Bi-sample Differencing* and *Bi-sample mean* manipulations. In other words, operating on *reliability observations series* to reveal concealed statistical knowledge. Experimentation based on observation over a stationary series as a controlled experiment. As an outcome of experiments, the differencing seems to be alleviating the trend and seasonality to a degree. The bi-sample averaging is observed to be hiding variant conditions.

1. Introduction

Once we obtain an observation series, whether it is stationary or not is controlled. In cases that this quality is not found, differencing type of interventions by subtracting the same equation with a preceding indexed y_{t-1} from both sides of an Auto Regression (AR) equation with y_t is considered (Sun et al. 2021). The target is fixing the situation by altering nothing in a mathematically accurate sense. This is actually checking whether there is a hidden stationary character within the series like a trend by forming a derivative one (Worden et al. 2019).

Would such an approach be applicable to a reliability series is the question aimed at being answered. There are varieties of techniques for identifying a stationary trend; very few of the studies consider the effects of changes for predictions such as Mean time between failure (MTBF) identifications. Consideration is made in a controlled manner once the series is independent and identical distributed according to a known classical distribution (Yucesan et. al. 2021), with a known mean (μ) and variance (σ) from observations.

This is a time for failure observations allowing for the prediction of a meaningful probability of a worse outcome. When operational duration is 3σ below the MTBF, there is less than or about 0.0013 chance of something going wrong. Depending on application, chance may be sufficiently safe, or it can be bad if the frequency of demand is high enough (Yucesan et. al. 2022).

To speak with clarity of this sort, we need stationary signals. The trends and seasonalities might be ruining the signal, hiding the underlying stationary character (Basu et al. 2009). To get around hiding effects, one addresses the mentioned operations, which are actually very well-known called filtering. Nevertheless, they can have an impact on the useful information from the series. Mentioned operations can be of the sort of a high or a low pass characteristic manner, namely a differencing and an averaging filter in respective ordering. The paper aims at observing the impacts of the mentioned techniques including changes on stationarity as a tool of measurement based on various tests like Kwiatowski, Phillips, Schmidt and Shin (KPSS) or Augmented Dickey and Fuller Test (ADF). Considerations will include the mean and variance impacts along with the existence of heteroscedasticity. Finally, information change obtained from the series as a result of the filter operations based on frequency is sought.

The rest of the document is organised as: first section introduction is followed by section 2. Stationarity Test Outcomes and section 3 Frequency Impact. A discussion on the findings is provided in section 4. Discussions, including a literature consideration and the paper is finalised by section 5 Conclusions.

2. Stationarity Tests Outcomes

KPSS and ADF tests are frequently referred to in the literature. These tests performed by known software such as

MATLAB with built-in functions, which can present the case of the observations better. The Student-t test is performed to see if the distribution of a given series to mentioned manipulations is different than that of a normal distribution with zero (0) mean (μ) and unity variance ($\sigma^2 = 1$). The resultant series variances (σ^2) are compared by first forming a series with the overall constant of one multiplied by variance outcome. Later the deviations from the mean in each of this variance derived series in squared terms $(S_i-\mu)^2$ was compared to this constant series pairwise. Here the S_i term represent each sample of the series. The Engel Arch test for Heteroscedasticity was also employed.

Table 1. Results of the statistical tests.

Test	Stu-t-μ	Stu-t-σ^2	ADF	KPSS	W/O Trend	Engle Arch
Original	In-Diff.	In-Diff.	Stat.	Non.	Stat.	Homosc.
Difference	In-Diff.	In-Diff.	Stat.	Stat.	Stat.	Heterosc.
Bi-Sample Ave.	In-Diff.	In-Diff.	Non.	Non.	Non.	Heterosc.

The outline of the results from Tab. 1 indicates that the processes of differencing and averaging impact the series in stationarity perspective. ADF test identify the original and difference series as stationary, on the other hand, bi-sample average series to be non-stationary. The default application of the test KPSS considers trend as present in regression formula. It is also possible to turn this off and check for a normal regression stationarity. The test fails when there is a trend control but indicates stationarity as it is removed. Difference operation solves this problem and gives a stationary outcome in both cases. The series originally presents homoscedastic behavior indicative of a variance stationarity; however, both filter operations on them end up with heteroscedasticity as a result of the Engel test.

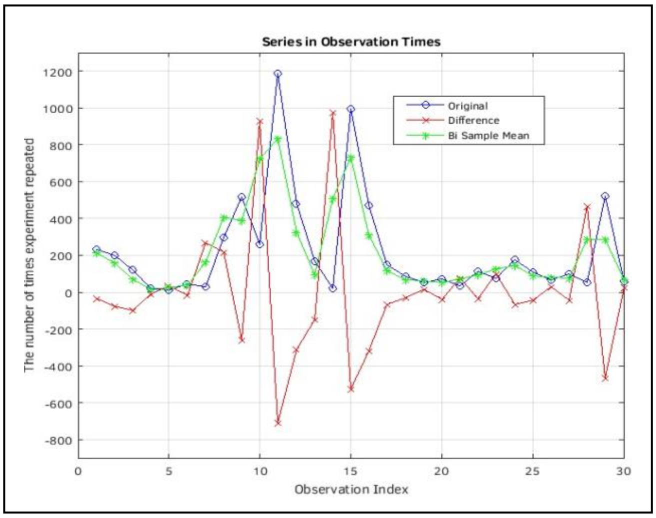

Figure 1. The observation series with 'o', the difference series is with 'x', and finally the bi-sample average series is marked with an asterisk '*'

The series subject to the study is composed from observations aiming to build up an MTBF figure. The same experiment of information query is repeated many times to see how many re-attempts can be made. As a failure occurs, the count of repetition is recorded, a reset is performed and the experiment is restarted. Based on these results, a data series from these observations is composed. The first 30 samples from all series are presented to give a basis of comparison in Fig. 1. The 'o' marked are from the original series, 'x' marked ones are from the series that is the outcome of the difference operations. '*' mark indicates the Bi-sample mean operations.

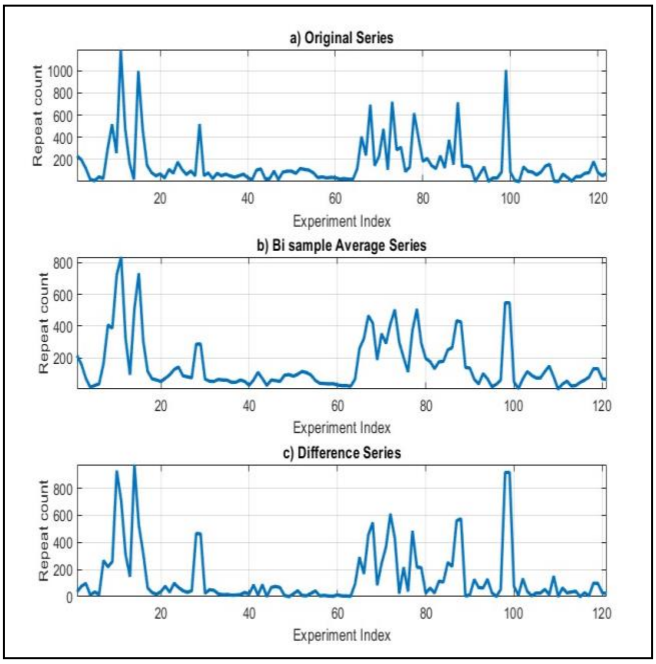

Figure 2. The inter failure duration series (a), along with the bi-sample mean (b) and absolute valued differenced series (c)

The original series, the output of the bi-sample mean process and the differencing can be seen in Fig. 2. The upper subplot is the original series. The second one is the averages and latter one being the differences series.

3. Frequency Impact

From the Fig.3, we can see that original series, shown with 'o' marks, has a rather flat frequency domain spectrum.

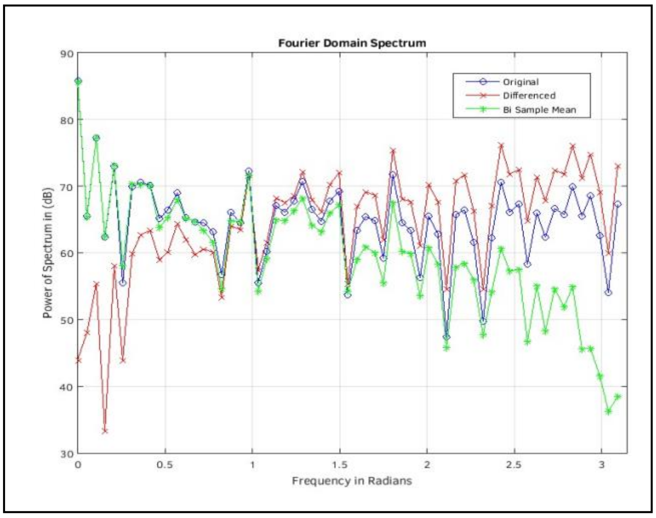

Figure 3. The observation series squared values in the Fourier frequency domain with 'o' for original series, the difference series is with 'x', and finally the bi-sample average series is marked with an asterisk '*'

The DC harmonics of the original are 15 dB stronger than those of the higher frequency components of the difference series. They are marked with 'x' marks. In this sense, the bi-sample average, shown by '*' marks, is removing some of the highest spectra impacting the power spectral density and autocorrelation outcome.

4. Discussion

A meaningful control is checking if the series at hand has persistent mean and variance within different limited time frames. It does not mean the series is stationary even if it has constant mean and variance but if it does not have such quality, it is not stationary (Parey et al. 2019; Muheialdin et al. 2014). This quality control can also be verified by a student-t test controlling μ and σ^2 is statistically different from overall values (Lee et al. 2008).

Differencing and averaging techniques aim to identify the hidden character that behaves stationary, yet is not directly apparent (James et al. 2011, Chambers et al. 1996). The differencing, if the series is monotonically increasing, alleviates the increments. It looks at the difference of samples, removing an immediate effect but revealing the hidden statistical character. With knowledge from signal processing about filtering, the bi-sample difference operation mostly removes low frequency components of the series. The Bi-sample Average takes the mean of two consecutive samples, removing the high frequency components from the signal. These effects are visible through Discrete Fourier Transform (DFT) or its rapid variant the Fast Fourier Transform (FFT) as available in Fig.3. These techniques can have an impact on μ parameter as well. Some studies investigate these mean adjustments (Presno et al. 2003).

The auto-correlation, variance and covariance are related and they are a part of the definition of the stationarity. Some of the tests try to identify if the homoscedasticity or heteroscedasticity exists in series or not for persisting variance character or dependence in a series (Chowdhury et al. 2017; Machiwal et al. 2008; Kipinski et al. 2011). Our observations indicate a shift to heteroscedasticity scenario as outcome of modifications.

Another method is to pre-filter these observations whence there exist seasonality (Taylor et al. 2003) Concentration in this study is to see what happens to knowledge in the signals, how the stationarity behaviors are affected along with the changes for bi-sample differencing and bi-sample averaging.

In Fig. 3, the low frequency terms are high for original and bi-sample average series. This could mean correlations with increasing lags are fading out, but also it tells the signals long-term lags are not similar to the early ones. There are parts more correlated and some parts that are less correlated, indicative of a weaker Independent Identical Distributed (IID) character. On the other hand, high frequency components or in other words short tern lags being similar is the case for the differenced sequence.

Seasonality is a trend persistent for a shorter time. The fact that it is uncommon that stationarity does not fail whence the trend is removed. As an outcome of observations in the series, cold days turn in higher and the warmer ones end up with the lower reliability indicating that the passive cooled device is susceptible to ambient air temperature. Once all trends are removed, this condition is sorted out as well. Bi-sample averaged series is resulting as non-stationary for both KPSS and ADF tests, contrary to all conditions yielding stationary outcomes for differenced series. This can be the case as local trends are more emphasized with bi-sample averaging technique.

The operations of differencing and averaging methods affect the series per useful qualities of predictions. A removed higher frequency component would, in some scenarios affect the variances. It means predictions for reliability estimates will change. On the other hand, if the Fig.1 presenting all three forms of the observation series is considered. In a comparison between all three, differencing technique removes the DC component of the series, which are useful for MTBF predictions.

With regard to Table 1, the μ and σ^2 stationarity with results of the differencing operations are granted per ADF and KPSS tests whereas Engel's heteroscedasticity test ends in the positive outcome for this quality. It means that the variance stationarity is affected negatively. With the difference interventions causing a deviation from the mean and variance could result in losing touch with simple known distributions like Exponential. The outcome of Engel's arch test indicates some concerns on this issue. On the other hand, if solely averaging based manipulations were performed, they could be misleading as well, hiding inconsistencies in events. The test results for averaging are not favorable in this case like the other method.

5. Conclusion

The DC term disappears after application of differencing technique. This is affecting the expectation (i.e. Mean) from the sequence and is a significant term for a probability prediction. The variance, considered as taking place along with high frequency components, is impacted by the averaging technique. This parameter is important also for making accurate probability estimates preventing higher costs to the producer or the consumer. It is interesting to note that the heteroscedasticity is observed after both of these operations. Such a finding indicates, the variance becoming time dependent.

The study tries to answer the research question: "what is the impact of differencing and bi-sample average on the reliability predictions like MTBF?". With observations on hand, MTBF and variance figures are impacted. The existing trends are erased by the differencing technique. The outliers as long success periods are lost at some level as outcome of averaging technique since high frequency findings are erased.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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