



# Comparative efficiency of Wald, Score, and Variance Stabilizing Confidence Intervals for the Coefficient of Variation of a Poisson Distribution: A Monte Carlo Study with Application to Nigeria's 2026 Lassa Fever Outbreak.

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## ABSTRACT:

The coefficient of variation (CV) is a popular, unit free measure of relative dispersion, and interval estimation of the CV for Poisson distributed count data has received growing attention.

This work assesses three confidence interval (CI) construction methods for the coefficient of variation (CV) of a Poisson distribution. The Three methods considered are Wald method, Score method, and Variance Stabilizing (VS) method. Each derived by first constructing a confidence interval for the Poisson mean and transforming to the relation  $K = \frac{1}{\sqrt{\mu}}$ . A Monte Carlo simulation (20,000 replications per case) assessed coverage probability and expected interval length across true means  $\mu = (1, 2, 5, 10, 20, 50)$  and sample sizes  $n = (10, 20, 30, 50, 100)$ . Results show that while all three methods approach nominal 95% coverage as  $n$  and  $\mu$  increase, the Wald interval is markedly unstable for small means and small samples ( $\mu = 1, n = 10$ ), showing both under coverage and a mean interval length several times larger than the Score and VS alternatives. Score and VS intervals maintain coverage closer to nominal levels with substantially shorter average widths throughout the parameter space considered, the three methods were then applied to a real, publicly reported dataset: weekly national counts of newly confirmed Lassa fever cases in Nigeria during the ongoing 2026 outbreak. In this application, all three methods produced closely agreeing intervals because the observed weekly mean was large enough to be outside the unstable region identified in simulation, however, the empirical sample CV (0.758) substantially exceeded the CV implied by the fitted Poisson mean (0.176), indicating pronounced over dispersion relative to the Poisson assumption, a finding with direct implications for outbreak monitoring applications of this methodology. Recommendations for specialist and guidance for additional research are discussed.

**Keywords:** coefficient of variation, confidence interval, Poisson distribution, coverage probability, Monte Carlo simulation, Lassa fever, Nigeria

## 1. Introduction

The coefficient of variation (CV) can be defined as the ratio of the standard deviation( $\sigma$ ) to the mean ( $\mu$ ). It is unit less measure of relative dispersion that allows comparison of variability across variables measured in different units or at different scales. Since its introduction by Karl Pearson, the Coefficient of variation (CV), has become a standard tool in reliability engineering, quality control, biomedical research, and more and more in the analysis of count data arising from tracking systems.

For data that follow a Poisson distribution, the mean and variance are equal, so the population CV reduces to the simple form  $\kappa = \frac{\sigma}{\mu} = \frac{\sqrt{\mu}}{\mu} = \frac{1}{\sqrt{\mu}}$ .

This property makes the Poisson CV entirely determined by the mean, and it also means that any confidence interval for the Poisson mean can, in principle, be transformed into a confidence interval for  $\kappa$ . Several such transformations have been proposed in the literature, motivated primarily by the search for intervals that maintain nominal coverage probability while minimizing expected length, particularly when the Poisson mean is small. A common situation in rare event and outbreak surveillance data.

Despite a growing body of simulation work comparing candidate intervals, several gaps remain: first, published comparisons have not always used a

common, shared simulation protocol, making it difficult to determine a single best performing method across studies. second, small mean, low count scenarios precisely the case of greatest practical relevance in rare disease and outbreak surveillance have often been pooled with larger mean scenarios rather than isolated as a distinct stress test.

Third, real data illustrations of these methods remain largely confined to a single epidemiological example (COVID 19 mortality counts), leaving open the question of how these intervals behave when applied to other real, and publicly available outbreak datasets.

Nigeria offers a timely and substantively important setting in which to examine this question.

As of epidemiological week 30 of 2026, the Nigeria Centre for Disease Control and Prevention (NCDC) had recorded 1,000 confirmed Lassa fever cases and 237 deaths nationally, representing a case fatality rate of 23.7%, higher than the corresponding period in 2025. Weekly confirmed case counts fluctuate considerably, for example, new confirmed cases rose from 74 in epidemiological week 6 to 82 in week 7, before later weeks showed values as low as 14 to 20, providing a genuine, low count, non-stationary Poisson type series against which candidate CV interval methods can be evaluated.

This paper has three objectives:

- (1) To assess three widely used mean inversion approaches to constructing a CV confidence interval for Poisson data, which is Wald, Score, and Variance Stabilizing (VS), using a unified Monte Carlo simulation protocol.
- (2) To identify the parameter regions (combinations of mean and sample size) in which the methods diverge most sharply.
- (3) To apply all three methods to a real, current, publicly reported Nigerian public health dataset, assessing both the practical agreement between methods and the adequacy of the underlying Poisson assumption itself.

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## 2. Literature Review

Interval estimation of the CV originates in the normal distribution literature, where McKay's

Chi-square based approximation and Vangel's refinement of it remain foundational reference methods. Panichkitkosolkul extended this line of work to the Poisson case, proposing an asymptotic confidence interval for the Poisson CV constructed via a confidence interval for the Poisson mean, and reporting via Monte Carlo simulation that the new interval attained closer to nominal coverage than both McKay and Vangel type constructions across the sample sizes and parameter values considered. A separate simulation study by the same author compared Wald, Wald with continuity correction, Score, and Variance Stabilizing intervals for the Poisson CV, concluding that the continuity corrected Wald interval achieved the closest coverage to nominal 0.95 and 0.90 levels.

More recent work has extended CV interval estimation to the zero inflated Poisson (ZIP) distribution, motivated directly by public health count data containing an excess of zero counts, Bayesian highest posterior density (HPD), standard and percentile bootstrap, and Markov Chain Monte Carlo methods were compared for the CV of a ZIP distribution and applied to daily COVID 19 death counts in Thailand, with the HPD method recommended overall. This remains to the authors' knowledge, the only substantial real data application of Poisson family CV interval estimation reported in the literature, and it addresses a zero inflated variant of the problem rather than the base Poisson case.

Taken together, the literature exhibits three notable gaps that motivate the present study:

first, different studies from the same methodological tradition have reported different 'best' methods (the asymptotic mean based interval in one paper, WCC in another), without a shared simulation protocol permitting direct comparison. Secondly, small mean, low count behaviour the regime of greatest applied relevance has generally been evaluated only as part of a broader parameter grid rather than isolated as a specific stress test. Third, real data validation beyond a single zero inflated epidemiological application is essentially absent from the published record.

### 3. Materials and Methods

#### 3.1 Definition of the Poisson coefficient of variation

Given that  $X_1, X_2, \dots, X_n$  be independent, identically distributed Poisson ( $\mu$ ) random variables with sample mean  $\bar{X} = \frac{\sum x_i}{n}$ . But recall that in Poisson Distribution,  $Var(X) = E(X) = \mu$ , the population coefficient of variation is  $K = \frac{\sigma}{\mu} = \frac{\sqrt{\mu}}{\mu} = \frac{1}{\sqrt{\mu}}$ , a strictly declining function of  $\mu$ . Therefore, any  $(1 - \alpha)100\%$  confidence interval  $(\mu_L, \mu_U)$  for  $\mu$  leads to a  $(1 - \alpha)100\%$  confidence interval for  $K$  given by  $(K_U, K_L)$  the bounds are transformed and their order is reversed because  $K$  is declining in  $\mu$ .

#### 3.2 Candidate confidence intervals for $\mu$

Three mean based confidence intervals were compared, each transformed into a CV interval as described above.

**Wald interval:**  $\mu_L, \mu_U = \bar{X} \mp Z_{\frac{\alpha}{2}} \sqrt{\frac{\bar{X}}{n}}$ , where  $Z_{\frac{\alpha}{2}}$  is the  $(1 - \alpha/2)$  quantile of the standard normal distribution. This is the simplest construction, relying on the asymptotic normality of  $\bar{X}$  without adjustment.

**Score interval:** obtained by inverting the score test statistic  $(\bar{X} - \mu)/\sqrt{(\mu/n)} = \pm Z_{\frac{\alpha}{2}}$ , which yields a quadratic equation in  $\mu$  with closed form roots. The Score interval respects the mean variance relationship of the Poisson distribution more directly than the Wald interval because the variance estimate used in the pivot is evaluated at the hypothesized  $\mu$  rather than at  $\bar{X}$ .

**Variance Stabilizing (VS) interval:** obtained by applying the transformation  $Y = \sqrt{\bar{X}}$ , for which  $Var(Y) \approx 1/(4n)$  is approximately independent of  $\mu$ . A symmetric Wald type interval is constructed on this stabilized scale and then back transformed by squaring, with the lower bound truncated at zero before squaring.

#### 3.3 Monte Carlo simulation design

For each association of true mean  $\mu = \{1, 2, 5, 10, 20, 50\}$  and sample size  $n = \{10, 20, 30, 50, 100\}$ , 20,000 independent samples of size  $n$  were generated from a Poisson( $\mu$ ) distribution. For each simulated sample, the three coefficient of variation (CV) confidence intervals (95% confidence intervals) were constructed as described above. Coverage probability was recorded as the proportion of the 20,000 replications for which the interval contained the true  $K = \frac{1}{\sqrt{\mu}}$ , and expected length was recorded as the mean of (upper bound, lower bound) across replications. All computations were carried out in Python 3 using NumPy for random number generation and SciPy for normal quantile calculation, with a fixed random seed to ensure reproducibility.

#### 3.4 Real data application: Nigeria 2026 Lassa fever outbreak

To illustrate the practical behaviour of the three methods, weekly national counts of newly confirmed Lassa fever cases in Nigeria during 2026 were compiled from publicly reported NCDC weekly situation report summaries, as disseminated through NCDC's own communications and independently reported by national news agencies (News Agency of Nigeria) for epidemiological weeks 6, 7, 18, 19, 25, 26, 27, 28, 29, and 30 (Table 2). These ten weeks represent the subset of 2026 epidemiological weeks for which a specific weekly new case count was independently verifiable in the public record at the time of writing. They are not a complete, contiguous weekly series for the full outbreak. Researchers seeking a complete and continuous weekly series for formal publication should obtain the full run of situation reports directly from NCDC's public situation report archive, noting that NCDC situation reports carry a data use notice restricting redistribution of the report documents themselves. The case counts reported here are drawn from

figures already independently published in the public press and are cited to their original sources rather than reproduced from the internal report layout.

The sample mean  $\bar{X}$ , sample standard deviation  $S$ , and empirical CV ( $\hat{S} = S/\bar{X}$ ) were computed from these ten weekly counts. The three confidence interval methods were then applied to construct 95% CIs for  $\mu$  and, via the transformation  $\kappa = \frac{1}{\sqrt{\mu}}$ , for the theoretical Poisson CV, allowing direct comparison against the empirical sample CV as a check on the underlying equal dispersion assumption

## 4. Result

### 4.1 Simulation study

Table 1 reports coverage probability and expected interval length for all three methods across the full simulation grid, averaged across all 30  $(\mu, n)$  combinations, the Score interval attained the coverage probability closest to the nominal 0.95 level (mean coverage 0.9496), followed by the VS interval (0.9486) and the Wald interval (0.9471). The methods diverge far more sharply in expected length: overall mean length was 0.140 for Score, 0.147 for VS, and 0.451 for Wald – a difference driven almost entirely by a single extreme scenario.

At  $\mu = 1$  and  $n = 10$  the smallest mean and smallest sample size considered, and the combination most representative of rare event or early outbreak surveillance counts, the Wald interval's mean length was 10.30, roughly seven to nine times the length of the Score (1.20) and VS (1.35) intervals at the same scenario, while simultaneously under covering at 92.8% against a 95% nominal target; this behaviour arises because the Wald interval for  $\mu$  can produce a lower bound near zero when  $\bar{X}$  is small, and because  $\mu = 12/\sqrt{\mu}$  diverges as  $\mu$  approaches zero, even a modest downward perturbation of the lower bound for  $\mu$  produces an extreme upper bound for  $\kappa$ . the Score and VS intervals, by anchoring the variance estimate to the boundary of the parameter space, avoid this instability, as  $\mu$  and  $n$  increase, all three methods converge toward comparable coverage and length, becoming practically indistinguishable for  $\mu = 13$  regardless of sample size.

**Table 1. Monte Carlo coverage probability and mean interval length for 95% CV confidence intervals, by true mean ( $\mu$ ) and sample size ( $n$ ); 20,000 replications per scenario. Shaded row indicates the unstable small-mean, small sample scenario discussed in the text.**

| $\mu$ (true mean) | $\kappa = 1/\sqrt{\mu}$ | N   | Wald coverage | Wald length   | Score coverage | Score length | VS coverage | VS length |
|-------------------|-------------------------|-----|---------------|---------------|----------------|--------------|-------------|-----------|
| 1                 | 1.0000                  | 10  | 0.9284        | <b>10.299</b> | 0.9648         | 1.196        | 0.9589      | 1.347     |
| 1                 | 1.0000                  | 20  | 0.9490        | 0.541         | 0.9458         | 0.464        | 0.9409      | 0.490     |
| 1                 | 1.0000                  | 30  | 0.9300        | 0.407         | 0.9453         | 0.371        | 0.9428      | 0.384     |
| 1                 | 1.0000                  | 50  | 0.9528        | 0.298         | 0.9490         | 0.283        | 0.9464      | 0.288     |
| 1                 | 1.0000                  | 100 | 0.9434        | 0.203         | 0.9472         | 0.198        | 0.9474      | 0.200     |
| 2                 | 0.7071                  | 10  | 0.9495        | 0.382         | 0.9470         | 0.327        | 0.9413      | 0.346     |
| 2                 | 0.7071                  | 20  | 0.9418        | 0.240         | 0.9496         | 0.225        | 0.9490      | 0.231     |
| 2                 | 0.7071                  | 30  | 0.9496        | 0.190         | 0.9533         | 0.182        | 0.9519      | 0.185     |
| 2                 | 0.7071                  | 50  | 0.9452        | 0.144         | 0.9504         | 0.140        | 0.9500      | 0.142     |
| 2                 | 0.7071                  | 100 | 0.9456        | 0.100         | 0.9486         | 0.098        | 0.9479      | 0.099     |
| 5                 | 0.4472                  | 10  | 0.9494        | 0.133         | 0.9449         | 0.127        | 0.9429      | 0.129     |
| 5                 | 0.4472                  | 20  | 0.9440        | 0.091         | 0.9497         | 0.089        | 0.9478      | 0.089     |
| 5                 | 0.4472                  | 30  | 0.9524        | 0.073         | 0.9558         | 0.072        | 0.9509      | 0.073     |
| 5                 | 0.4472                  | 50  | 0.9495        | 0.056         | 0.9469         | 0.056        | 0.9506      | 0.056     |
| 5                 | 0.4472                  | 100 | 0.9456        | 0.039         | 0.9465         | 0.039        | 0.9466      | 0.039     |
| 10                | 0.3162                  | 10  | 0.9484        | 0.064         | 0.9528         | 0.063        | 0.9530      | 0.063     |
| 10                | 0.3162                  | 20  | 0.9456        | 0.045         | 0.9480         | 0.044        | 0.9480      | 0.044     |
| 10                | 0.3162                  | 30  | 0.9499        | 0.036         | 0.9473         | 0.036        | 0.9467      | 0.036     |
| 10                | 0.3162                  | 50  | 0.9465        | 0.028         | 0.9476         | 0.028        | 0.9469      | 0.028     |
| 10                | 0.3162                  | 100 | 0.9492        | 0.020         | 0.9469         | 0.020        | 0.9493      | 0.020     |
| 20                | 0.2236                  | 10  | 0.9464        | 0.032         | 0.9483         | 0.031        | 0.9475      | 0.031     |
| 20                | 0.2236                  | 20  | 0.9555        | 0.022         | 0.9566         | 0.022        | 0.9559      | 0.022     |
| 20                | 0.2236                  | 30  | 0.9509        | 0.018         | 0.9540         | 0.018        | 0.9512      | 0.018     |
| 20                | 0.2236                  | 50  | 0.9488        | 0.014         | 0.9474         | 0.014        | 0.9489      | 0.014     |

|    |        |     |        |       |        |       |        |       |
|----|--------|-----|--------|-------|--------|-------|--------|-------|
| 20 | 0.2236 | 100 | 0.9472 | 0.010 | 0.9474 | 0.010 | 0.9473 | 0.010 |
| 50 | 0.1414 | 10  | 0.9482 | 0.012 | 0.9498 | 0.012 | 0.9491 | 0.012 |
| 50 | 0.1414 | 20  | 0.9486 | 0.009 | 0.9473 | 0.009 | 0.9487 | 0.009 |
| 50 | 0.1414 | 30  | 0.9516 | 0.007 | 0.9497 | 0.007 | 0.9499 | 0.007 |
| 50 | 0.1414 | 50  | 0.9514 | 0.006 | 0.9506 | 0.006 | 0.9519 | 0.006 |
| 50 | 0.1414 | 100 | 0.9485 | 0.004 | 0.9487 | 0.004 | 0.9485 | 0.004 |

#### 4.2 Application to Nigeria's 2026 Lassa fever outbreak

Table 2 presents the ten weekly national confirmed case counts used in the applied illustration. The observed values ranged from 14 (week 27) to 82 (week 7), with sample mean  $(\bar{X}) = 32.4$  and sample standard deviation  $S = 24.56$ , yielding an empirical sample coefficient of variation of  $\hat{S} = S/\bar{X} = 0.758$ .

**Table 2. Reported Weekly newly confirmed Lassa fever cases in Nigeria, for the first 30 weeks, 2026 (relevant epidemiological weeks. As reported by the Nigeria centre for Disease Control and prevention (NCDC) situation report summaries as reported in the public press).**

| Epidemiological Week | Newly Confirmed Lassa Fever Cases in Nigeria. |
|----------------------|-----------------------------------------------|
| Week 6               | 74                                            |
| Week 7               | 82                                            |
| Week 18              | 22                                            |
| Week 19              | 17                                            |
| Week 25              | 22                                            |
| Week 26              | 31                                            |
| Week 27              | 14                                            |
| Week 28              | 25                                            |
| Week 29              | 20                                            |
| Week 30              | 17                                            |

Table 3 presents the three 95% confidence intervals for the Poisson mean and the corresponding transformed intervals for the theoretical Poisson CV. Because the observed weekly mean (32.4) is well outside the unstable small mean region identified in the simulation study, all three methods produced closely agreeing intervals: Wald (0.1668, 0.1861), Score (0.1664, 0.1855), and VS (0.1666, 0.1858), with interval widths differing by less than 0.001 across all three methods.

**Table 3. Ninety-five percent confidence intervals for the Poisson mean and the transformed coefficient of variation, applied to the 2026 Nigerian weekly Lassa fever data.**

| Method                    | 95% CI for $\mu$ (weekly mean incidence) | 95% CI for $K$ (coefficient of variation) | Interval width |
|---------------------------|------------------------------------------|-------------------------------------------|----------------|
| Wald                      | (28.872, 35.928)                         | (0.1668, 0.1861)                          | 0.0193         |
| Score                     | (29.059, 36.125)                         | (0.1664, 0.1855)                          | 0.0191         |
| Variance Stabilizing (VS) | (28.968, 36.024)                         | (0.1666, 0.1858)                          | 0.0192         |

Particularly, the theoretical Poisson coefficient of variation (CV) suggested by the fitted mean (approximately 0.176, the midpoint of all three intervals) is significantly smaller than the empirical sample Coefficient of variation (CV) computed directly from the ten weekly counts (0.758). This fourfold discrepancy indicates substantial over dispersion relative to the Poisson assumption, the week to week variability in confirmed case counts is far greater than the Poisson model, which ties variance rigidly to the mean would predict.

## 5. Discussion

Two findings stand out in this study. The simulation results confirm and extend previous reports that classical Wald type intervals for the Poisson CV are unreliable precisely in the small mean, small sample regime most relevant to rare event and early outbreak surveillance, while the Score and Variance Stabilizing alternatives remain stable throughout, with a direct practical implication. An analyst monitoring a new or low incidence outbreak (weekly counts in the single digits) should avoid the simple Wald construction and prefer Score or VS interval, despite they all perform roughly equivalently as counts become moderately large. The applied illustration, however, points to a more fundamental limitation than the choice of these three interval methods: the Poisson assumption. The fourfold gap between the theoretical Poisson CV and the empirical sample CV in the Lassa fever series indicates that weekly national case counts during an active, evolving outbreak are substantially over dispersed relative to a Poisson model, most plausibly because the underlying transmission intensity is not constant across the observation window early weeks captured an escalating phase of the outbreak while later weeks reflect a comparatively more controlled phase.

None of the three Poisson based interval methods compared here can be expected to yield a valid confidence statement about the CV, however well each performs under the correctly specified Poisson simulation, and this finding echoes and gives an applied illustration of the previously identified methodological gap that mean inversion CV intervals rest on an unexamined transfer of Poisson mean interval properties to CV inference; over dispersion robust alternatives (e.g., negative binomial based or quasi Poisson CV intervals) would then merit direct empirical comparison against the classical Poisson methods on the same real surveillance series.

These results should be read alongside the study's data limitations, discussed next.

## 6. Limitations

Several limitations qualify these findings. First, the realdata illustration uses ten non contiguous epidemiological weeks rather than a complete, continuous weekly series for 2026, because only these weeks' national counts could be independently verified from publicly reported summaries at the time of writing, a full series replication using the complete run of NCDC situation reports, obtained directly from NCDC in accordance with its data use terms, is needed before this application could be considered.

Secondly, the applied analysis treats national weekly counts as a single homogeneous series, whereas the outbreak's geographic concentration 86% of confirmed 2026 cases were reported from just five states, means a state stratified analysis would likely reveal different, possibly more homogeneous dispersion patterns at the sub national level.

Thirdly, the simulation study, while extensive, considers only equally spaced grid values of  $\mu$  and  $n$  and does not incorporate the specific overdispersion structure observed in the real data, a simulation calibrated to a negative binomial or time varying mean data generating process would more directly test method performance under the conditions actually observed in Section 4.2.

Finally, only three of the several CV interval methods proposed in the literature (e.g., continuity corrected Wald, McKay and Vangel type asymptotic intervals, and Bayesian/bootstrap approaches) were compared here. A more exhaustive comparison including these additional methods on both simulated and real data remains an open task.

## 7. Conclusion and Recommendations

Among the three mean inversion confidence interval methods compared for the coefficient of variation of a Poisson distribution, the Score and Variance Stabilizing intervals offer more stable coverage and substantially shorter expected length than the Wald interval, with the advantage concentrated in small mean, small sample scenarios most relevant to rare event and early outbreak monitoring. Applied to Nigeria's 2026 Lassa fever outbreak data, all three methods agreed closely at the observed sample size, but the analysis surfaced a more consequential finding. Substantial over dispersion of real surveillance counts relative to the Poisson assumption that underlies all three methods.

We recommend that (1) practitioners analysing low count surveillance data prefer the Score or VS interval over the simple Wald interval.

(2) Any application of Poisson CV methodology to real surveillance data include a preliminary check of the equal dispersion assumption (e.g., a dispersion test comparing sample variance to sample mean).

(3) future work directly compare Poisson based and over dispersion robust CV interval methods on the same complete, continuous outbreak series, ideally obtained through formal data sharing arrangements with the reporting public health agency.

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