Revised Decision Criteria for Before-and-After Analyses

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ABSTRACT

Because better experimental designs utilizing control sites are not always feasible, a simple before-and-after analysis is commonly used to analyze accident rates and other counted events. Treating the number of events counted before some experimental change as a known constant rather than as a random variable is a fundamental conceptual error that falsely inflates the confidence level at which the experimental change can be judged to have had a significant effect. For example, a reduction in the number of accidents observed after some improvement has been implemented may be judged to be statistically significant when, in fact, it is primarily the result of the chance occurrence of an unusually high "before" count, a typical manifestation of the "regression-to-the-mean" phenomenon. By properly treating the initial count as a random variable, at least a portion of this problem is avoided. New tables are developed to provide more appropriate decision criteria for applications of this type.

The accident history at a particular site is often the only basis for measuring the effectiveness of a safety improvement. The number of accidents observed during equal periods of time before and after the improvement was implemented are compared to determine whether or not a reduction can be attributed to something other than random chance. This same approach may also be used to judge whether or not an increase in accident frequency at a site warrants remedial action. Although it is highly desirable to incorporate control sites into such analyses to screen out the effects of time, traffic volume, or other extraneous factors, this is not always possible. Consequently, decisions must often be based solely on the "before" and "after" accident counts at a particular location.

Because the typical time and exposure conditions associated with the occurrence of accidents closely approximate the theoretical conditions that give rise to the Poisson distribution, it is usually assumed that accidents are Poisson-distributed for analytical purposes. One method of analysis, presented in graphical form in the Highway Safety Evaluation (HSE) Procedural Guide (1,p.114), treats the before count as a known Poisson mean and indicates the percent change in the after count that must be observed to be judged statistically significant at four selected confidence levels. This graph is shown in Figure 1.

There are at least three things wrong with the method in the HSE Procedural Guide:

1. Unless the before period is quite long, which usually is not the case, it is not appropriate to treat the accident count as a known constant. To be properly evaluated, it must be regarded as a random variable that provides an estimate of the underlying accident potential for that particular site.
2. This conceptual error leads to a second one, the assumption that the same decision criteria can be used to test for either significant decreases or significant increases in accident frequency. This is approximately correct when the before count is truly known but is not correct when it must be treated as a random variable.
3. The Accident Research Manual (2,p.39) states that one of the most important causes of erroneous conclusions in highway-related evaluations is the regression-to-the-mean phenomenon. To illustrate this effect by example, the practice of applying safety improvements only to those locations having the highest accident frequencies--some of which are due in part to random chance and which would have appeared to improve even if nothing were done--tends to falsely inflate the level of significance attributed to the various improvements. That this is not a problem to be casually disregarded is evidenced in a statement by Persaud and Hauer (3,p.44) that this effect is "consistent, real, and nothing short of dramatic." Because the method in the HSE Procedural Guide treats the before observation as a known, rather than recognizing it as a random variable, it is particularly susceptible to this common shortcoming.

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CORRECTIVE MEASURES

There are several methods by which the before count can be treated as a random variable. Three specific methods that are offered in lieu of that in the HSE Procedural Guide will be referred to as the chi-square, binomial, and modified binomial methods, respectively. An outline of all four methods follows.

Method in HSE Procedural Guide

The before count is taken to be a known Poisson mean. For a series of possible before counts, terms of the Poisson distribution are summed as indicated in Equation 1 to determine the after counts necessary to be judged statistically significant at (or above) the desired levels of confidence. (Alternatively, nearly the same results can be obtained by approximating the Poisson distribution with a normal distribution having $\mu = \sigma^2$ = Poisson mean.) These results are then converted to percentages and used to plot the curves in Figure 1.

$$\alpha = \sum_{x=X_1}^{x=X_2} \lambda^x e^{-\lambda}/x! \quad (1)$$

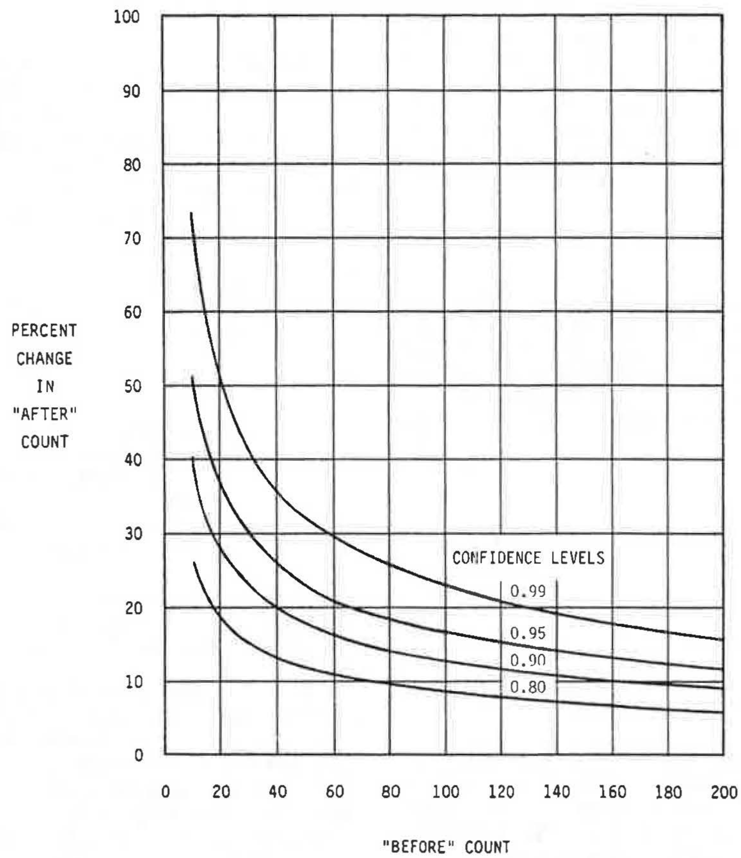

FIGURE 1 Graphical decision criteria in HSE Procedural Guide.

where

α = probability that $X_1 \leq x \leq X_2$, significance level of test;
λ = Poisson mean (assumed equal to before count);
e = base of natural logarithms (2.71828...); and
X_1, X_2 = summation limits.

Let the number of after events be designated by X. To determine whether or not X represents a significant departure from the (assumed) true mean value of λ, the appropriate area under the Poisson distribution is computed. If X is less than λ so that a possible decrease in the number of events is under test, the summation limits are $X_1 = 0$ and $X_2 = X$. If X is greater than λ, the limits are $X_1 = X$ and $X_2 = \infty$. (For practical purposes, the computational procedure is terminated whenever subsequent terms become insignificant.) The value of α obtained in this manner represents the single-tailed significance level at which the observed after count of X can be judged to be significantly different from the (assumed known) before count of λ. To plot the curves shown in Figure 1, each X value is converted to a percent change and the confidence level is taken to be $1 - \alpha$.

For example, suppose that during the 2 years preceding the installation of a skid-resistant overlay, there were 10 accidents in which slipperiness was a factor. In the 2 years following the installation, there were five such accidents. It is desired to know at what level of confidence this degree of reduction can be attributed to anything other than random chance. (It is assumed that traffic volume, an indicator of exposure representing the opportunity for accidents to occur, has remained essentially constant and that no other pertinent factors have changed. The count values used in this example have been chosen to be quite low to simplify the illustration.) The values computed with Equation 1 are presented in Table 1.

Because accident count is a discrete variable, it usually is not possible to match the desired confidence levels in Figure 1 exactly. To be conservative, the critical after counts are selected so that their computed significance levels (α) are less than or equal to those associated with the stated confidence levels ($1 - \alpha$). Although the resulting curves are not strictly continuous, it is a practical expedient to plot them as such in Figure 1.

The previously stated example, in which there were 10 accidents before and 5 accidents after a safety improvement was installed, may now be analyzed. Under the assumption that the before count is

TABLE 1 Illustration of Method Used in HSE Procedural Guide

After Count (X)	Percent Change from Before Count of $\lambda = 10$	Cumulative Probability[a] (significance level, α)	
0	100	0.000045	
1	90	0.000499	
2	80	0.002769	($\alpha \leq 0.01$)
3	70	0.010336	
4	60	0.029253	($\alpha \leq 0.05$)
5	50	0.067086	($\alpha \leq 0.10$)
6	40	0.130142	($\alpha \leq 0.20$)
7	30	0.220221	

[a]Computed with Equation 1 using before count of $\lambda = 10$.

a known constant, it is observed from Table 1 that this particular count combination corresponds to a significance level of $\alpha = 0.067$. If Figure 1 is used, this point falls between the 0.90 and 0.95 confidence lines, a result that might lead the highway agency to conclude that the safety improvement is responsible for a significant reduction in accidents.

CHI-SQUARE METHOD

Of the various methods by which the before count may be treated as a variable, the simplest (but not necessarily the best) is based on the chi-square distribution. It is well known that a variable that can be expressed in the form given by Equation 2 is approximately chi-square distributed (4,p.238) with k - 1 degrees of freedom.

$$\chi^2 = \sum_{i=1}^{i=k} [(O_i - E_i)^2/E_i] \qquad (2)$$

where

χ^2 = chi-square statistic,
O = observed count,
E = theoretically expected count, and
k = number of different categories.

For the present application, there are only two possible categories, the before and after counts, which will be designated Y and X, respectively. Under the null hypothesis that X and Y are both estimates of the same underlying Poisson mean, the best estimate of the theoretically expected count is the average of the two. Therefore, $E_1 = E_2 = (X + Y)/2$. Equation 2 then reduces to

$$\chi^2 = (X - Y)^2/(X + Y) \qquad (3)$$

where X is the after count and Y is the before count with one degree of freedom. Because there is some difference of opinion in the literature about whether a continuity correction should be applied, no such adjustment has been made.

Using the same example with a before count of Y = 10 and an after count of X = 5, Table 2 has been prepared. These results are substantially different from those in Table 1 where, based on the assumption that the before count can be taken as a known constant, a reduction of 50 percent was required to achieve statistical significance at the $\alpha = 0.10$ level. In Table 2, using the chi-square method to treat the before count as a random variable, a reduction of 70 percent is required to achieve essentially the same level of significance. By this procedure, a reduction in accident count from Y = 10 to X = 5 would not be likely to be judged statistically significant.

TABLE 2 Illustration of Chi-Square Method

After Count (X)	Percent Change from Before Count of Y = 10	Chi-Square Value[a] (χ^2)	Cumulative Probability[b] (significance level, α)	
0	100	10.00	0.002	
1	90	7.36	0.007	($\alpha \leq 0.01$)
2	80	5.33	0.021	($\alpha \leq 0.05$)
3	70	3.77	0.052	($\alpha \leq 0.10$)
4	60	2.57	0.109	
5	50	1.67	0.196	($\alpha \leq 0.20$)
6	40	1.00	0.317	

[a]Computed with Equation 3 using before count of Y = 10.
[b]Obtained from chi-square table (or suitable computer algorithm).

BINOMIAL METHOD

A statistically more efficient method to perform this analysis is based on the binomial distribution (5,p.140). Under the null hypothesis that there has truly been no change, this procedure assumes that a given total number of events will be distributed between the before and after categories as a binomial variable with p = 0.5. The following equation applies:

$$\alpha = 0.5^N \sum_{x=X_1}^{x=X_2} N!/[x!(N - x)!] \qquad (4)$$

where

α = probability that $X_1 \leq x \leq X_2$, significance level of test;
N = total count = X + Y;
X = after count;
Y = before count; and
X_1, X_2 = summation limits.

If X is less than Y, the appropriate summation limits are $X_1 = 0$ and $X_2 = X$. When X is greater than Y, the summation limits are $X_1 = X$ and $X_2 = X + Y = N$.

For the example that has been used thus far, the before and after counts are Y = 10 and X = 5, respectively. Using Equation 4, the values in Table 3 are obtained. Although this will not always be the case, it is observed in this example that this method produces slightly different critical values than those obtained by the chi-square method in Table 2. It will be demonstrated in a subsequent section that, in the long run, this procedure tends to produce a slightly greater percentage of correct decisions than the chi-square method.

TABLE 3 Illustration of Binomial Method

After Count (X)	Percent Change from Before Count of Y = 10	Total Count (N)	Cumulative Probability[a] (significance level, α)	
0	100	10	0.000977	
1	90	11	0.005859	($\alpha \leq 0.01$)
2	80	12	0.019287	
3	70	13	0.046143	($\alpha \leq 0.05$)
4	60	14	0.089783	($\alpha \leq 0.10$)
5	50	15	0.150879	($\alpha \leq 0.20$)
6	40	16	0.227249	

[a]Computed with Equation 4 using before count of Y = 10.

MODIFIED BINOMIAL METHOD

Because these methods deal with discrete data, it is seldom possible to control the confidence level $(1 - \alpha)$ at precisely the desired value. Consequently, it is customary to set up decision criteria that are conservative so that the actual confidence level will never be less than the indicated value. If it were desired to have decision criteria that would produce very nearly the stated confidence levels in the long run, a slight modification of the binomial method may be made. Rather than selecting the critical after counts so that the confidence levels are always greater than or equal to the stated values, they can be chosen on the basis of being closest to the stated values, whether larger or smaller. By this procedure, the decision criteria (tables or graphs) would cause individual decisions to be made at confidence levels slightly larger or smaller than the desired values but in a random fashion such that the averages would tend to be close to the desired values in the long run. If this approach were applied to the values in Table 3, the first three critical values would remain unchanged but, at $\alpha = 0.20$, the critical after count would be taken to be 6, representing a 40 percent reduction. This procedure will be included among those tested in a subsequent section.

SUMMARY OF THE FOUR EXAMPLES

Based on a hypothetical situation in which there was a before count of 10, the percent changes required to achieve statistical significance at the selected confidence levels are given in Table 4. For these

TABLE 4 Summary of Examples

	Percent Reduction[a] Required for Statistical Significance at Selected Confidence Levels			
Analysis Method	0.99	0.95	0.90	0.80
HSE Procedural Guide	90	60	50	40
Chi-square	90	80	70	50
Binomial	90	70	60	50
Modified binomial	90	70	60	40

[a]Based on before count of 10.

examples, the three alternate procedures all require larger percent changes than the HSE method before statistical significance can be claimed. To provide a better impression of the magnitude of the difference over a wide range of possible input data, the $1 - \alpha = 0.95$ curves are plotted for the HSE and binomial methods in Figure 2. It can be seen from this figure that the difference is greater when the test concerns an increase rather than a decrease in the counted data, that there is a larger difference in the realm of smaller counts for both decreases and increases, and that the difference is still fairly substantial even for large counts.

Like the binomial method, the chi-square and modified binomial methods exhibit very nearly the same behavior as that shown in Figure 2. In order to judge which of the three alternate methods is best, it is necessary to test their performance in situations in which the null hypothesis is true and also when it is false.

NULL AND POWER TESTS

Computer simulation tests were run to evaluate the performance of the three alternate methods and to compare their performance with that of the HSE method. The first, shown in Figure 3, is a null test but was run primarily to demonstrate that the Poisson random generator was working properly. With the possible exception of the kurtosis, the parameters of the randomly generated distribution are seen to agree very closely with the desired theoretical values.

For this particular run, the four analysis methods were applied to 1,000 different pairs of random Poisson variates and the results (accept or reject the null hypothesis of no difference) were counted. Because the null hypothesis was true (the means of the before and after populations were both equal to 10) and the test was run at the $\alpha = 0.05$ significance level, it would be considered a desirable result if the tests falsely rejected the null hypothesis approximately 5 percent of the time. It is seen

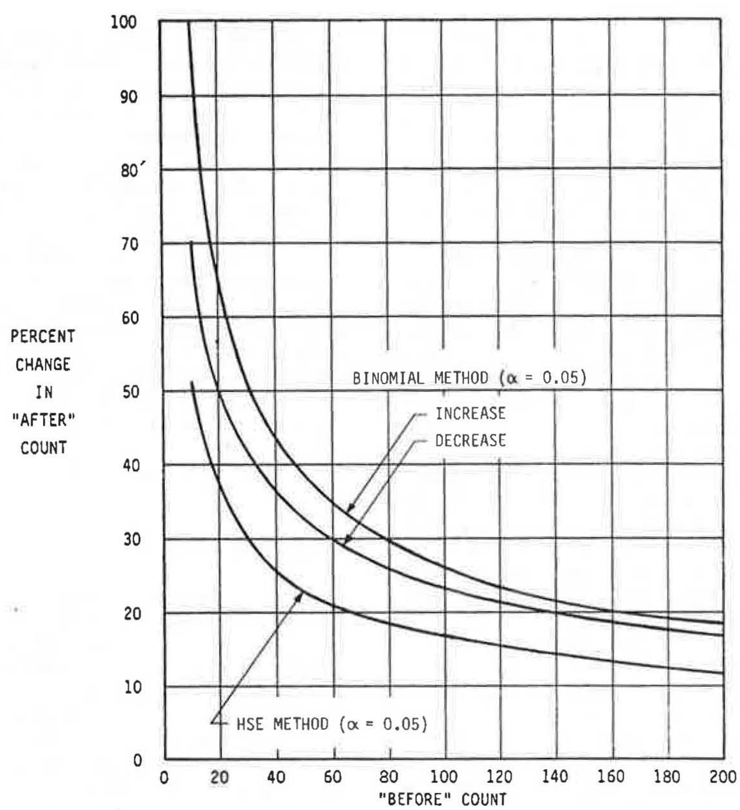

FIGURE 2 Comparison of binomial method with method in HSE Procedural Guide.

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run poistest
EXECUTION BEGINS...

ENTER'SIGNIFICANCE LEVEL, POISSON MEAN, NUMBER OF REPLICATIONS,
AND RANDOM GENERATOR SEED NUMBER
?
0.05 10 1000 7654321
```

CHECK OF POISSON RANDOM GENERATOR

PARAMETER	DESIRED	OBTAINED
MEAN	10.00	10.11
VARIANCE	10.00	9.86
SKEW	0.32	0.36
KURTOSIS	0.10	0.35
PAIRWISE CORRELATION	0.0	0.03

COMPARISON OF TWO POISSON POPULATIONS

	RELATIVE FREQUENCY OF FALSELY REJECTING THE NULL HYPOTHESIS (BASED ON 1000 REPLICATIONS)	
ANALYSIS METHOD	DESIRED	OBTAINED
HSE PROCEDURAL GUIDE	0.050	0.125
CHI-SQUARE	0.050	0.021
BINOMIAL	0.050	0.028
MODIFIED BINOMIAL	0.050	0.043

FIGURE 3 First computer run to demonstrate simulation concept.

from Figure 3 that the rejection rate for the HSE method is considerably more than 5 percent. This is the result of treating the before count as a constant rather than as a random variable. The rejection rates for the chi-square and binomial methods are both less than 5 percent, an expected result because these methods are known to be conservative. The modified binomial method produces a rejection rate quite close to 5 percent, as intended.

A more complete series of null tests is shown in Figure 4. The same simulation procedure has been used except that, in addition to the empirically derived rejection rates, lower and upper confidence limits have been printed in parentheses to provide an impression of the reliability of the results. The confidence limits are of the equal-likelihood type (6,p.453) and are unsymmetrical.

Figure 4 includes several combinations of significance level and Poisson mean and produces essentially the same results as were observed in Figure 3. The HSE method falsely rejects the null hypothesis much too often whereas the chi-square and binomial methods reject it somewhat less often than probably could be tolerated. The modified binomial method has rejection rates very close to the significance level at which the tests were run.

A series of power tests, all run at a significance level of $\alpha = 0.05$, is shown in Figure 5. For these tests, various combinations of true Poisson means have been used. In every case, the true population means are different and it is desired that the analysis methods be capable of recognizing these differences by rejecting the null hypothesis a large percentage of the time. Obviously, the more pronounced differences will produce higher rejection rates.

At first glance, it might appear that the HSE method is superior because it has rejection rates higher than the other three methods. It must be recognized, however, that this is largely the result of its tendency to reject too often, as demonstrated in Figure 4. Its use would be acceptable only if there were little or no concern about the many times it falsely rejects the null hypothesis. Between the chi-square and binomial methods, the latter appears to be the better procedure. Although the differences are small, it consistently outperforms the chi-square method in both the null tests and the power tests. For the user willing to accept that the modified binomial method will falsely reject the null hypothesis about the proper percentage of time in the long run, still greater power can be obtained, as seen in the last column of Figure 5.

REVISED DECISION CRITERIA

Suitable decision criteria to judge the significance of changes between before and after counts may be derived by any of the three alternate methods--chi-square, binomial, or modified binomial--and may be put in either tabular or graphical form. The critical after values may be presented as percent changes from the before counts (as is presently done in the HSE Procedural Guide) or as direct counts. Because this is believed to have the greatest potential usefulness, the revised decision criteria presented in

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run nulltest
EXECUTION BEGINS...

ENTER NUMBER OF REPLICATIONS AND RANDOM GENERATOR SEED NUMBER
?
1000 9876543
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DESIRED RELATIVE FREQUENCY OF FALSE REJECTION	TRUE POISSON MEAN	RELATIVE FREQUENCY OF FALSE REJECTION WITH LOWER AND UPPER ALPHA/2 = 0.025 CONFIDENCE LIMITS: HSE PROCEDURAL GUIDE	CHI-SQUARE	BINOMIAL	MODIFIED BINOMIAL
		(0.036)	(0.000)	(0.001)	(0.003)
0.01	10	0.048	0.003	0.004	0.008
		(0.063)	(0.009)	(0.010)	(0.016)
		(0.048)	(0.000)	(0.001)	(0.003)
0.01	20	0.062	0.002	0.004	0.007
		(0.079)	(0.007)	(0.010)	(0.014)
		(0.041)	(0.001)	(0.001)	(0.003)
0.01	50	0.054	0.005	0.005	0.007
		(0.070)	(0.012)	(0.012)	(0.014)
		(0.129)	(0.014)	(0.017)	(0.031)
0.05	10	0.151	0.022	0.026	0.043
		(0.175)	(0.033)	(0.038)	(0.058)
		(0.126)	(0.013)	(0.020)	(0.032)
0.05	20	0.147	0.021	0.030	0.044
		(0.171)	(0.032)	(0.043)	(0.059)
		(0.113)	(0.019)	(0.027)	(0.033)
0.05	50	0.133	0.028	0.038	0.045
		(0.156)	(0.040)	(0.052)	(0.060)
		(0.173)	(0.035)	(0.046)	(0.073)
0.10	10	0.197	0.047	0.060	0.090
		(0.223)	(0.062)	(0.077)	(0.109)
		(0.191)	(0.035)	(0.060)	(0.087)
0.10	20	0.216	0.047	0.076	0.105
		(0.243)	(0.062)	(0.094)	(0.126)
		(0.187)	(0.036)	(0.064)	(0.078)
0.10	50	0.212	0.049	0.080	0.096
		(0.239)	(0.064)	(0.099)	(0.116)

FIGURE 4 Series of null tests.

Figure 6 are based on the binomial method and have been put in tabular form with the critical after values listed as percent changes.

SUMMARY AND CONCLUSIONS

It is often necessary to use the simple before-and-after analysis of counted events to analyze accident rates or other phenomena. By failing to recognize the before count as a random variable, various safety improvements may be incorrectly judged to be significantly beneficial when, in fact, the apparent benefit may be due only to random chance. The degree to which such misapplications ultimately affect the conclusions of research studies or influence policy decisions is not known, but the potential harm of specifying the wrong material or product, or of establishing a less-than-optimal policy or design, is recognized to be substantial. An error of this type will seldom be an isolated case; it will be repeated with each subsequent application of the product or design standard.

In the case of simple before-and-after analyses, this problem can be alleviated by properly treating the before count as a random variable. Three methods for doing this were presented and one of them, a procedure that uses the binomial distribution to perform a hypothesis test of the equality of two Poisson populations, was used to develop tables of revised decision criteria suitable for applications of this type. It should be noted, however, that this does not correct for the regression-to-the-mean effect, a problem that may forever plague analysts when the test sites are not randomly selected.

The major impact of the new tables is that it will be more difficult to demonstrate that a safety improvement is significantly beneficial. Similarly, it will also be less likely that an apparent increase in accident frequency will incorrectly be interpreted to be real when, in fact, it is due only to chance. In either case, it is important to use the most appropriate analytical tools available. To quote again from the Accident Research Manual (2,p.27), "only with information from rigorous evaluations can sound administrative decisions be made."

AUTHOR'S NOTE

After presenting this paper, I became aware of an extensive set of tables prepared by Hauer (7) at the

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run powrtest
EXECUTION BEGINS...

ENTER NUMBER OF REPLICATIONS, SIGNIFICANCE LEVEL OF TESTS, AND RANDOM
GENERATOR SEED NUMBER
?
1000 0.05 1234567
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TRUE POISSON MEANS		RELATIVE FREQUENCY OF CORRECT REJECTION AT ALPHA OF 0.050 WITH ALPHA/2 = 0.025 CONFIDENCE LIMITS			
BEFORE	AFTER	HSE PROCEDURAL GUIDE	CHI-SQUARE	BINOMIAL	MODIFIED BINOMIAL
10	5	(0.434) 0.465 (0.496)	(0.229) 0.256 (0.284)	(0.258) 0.286 (0.315)	(0.342) 0.372 (0.403)
10	3	(0.695) 0.724 (0.752)	(0.457) 0.488 (0.519)	(0.492) 0.524 (0.555)	(0.592) 0.623 (0.653)
10	1	(0.932) 0.948 (0.961)	(0.810) 0.835 (0.858)	(0.812) 0.836 (0.858)	(0.862) 0.884 (0.903)
20	15	(0.291) 0.320 (0.350)	(0.099) 0.118 (0.140)	(0.131) 0.153 (0.177)	(0.172) 0.196 (0.222)
20	10	(0.647) 0.677 (0.706)	(0.405) 0.436 (0.467)	(0.458) 0.489 (0.520)	(0.524) 0.555 (0.586)
20	5	(0.956) 0.969 (0.979)	(0.865) 0.886 (0.905)	(0.885) 0.905 (0.922)	(0.920) 0.937 (0.951)
50	45	(0.242) 0.269 (0.298)	(0.056) 0.071 (0.089)	(0.089) 0.108 (0.129)	(0.113) 0.133 (0.156)
50	40	(0.380) 0.411 (0.442)	(0.161) 0.185 (0.211)	(0.216) 0.242 (0.270)	(0.245) 0.272 (0.301)
50	35	(0.623) 0.653 (0.683)	(0.334) 0.364 (0.395)	(0.421) 0.452 (0.483)	(0.465) 0.496 (0.527)

FIGURE 5 Series of power tests.

EVENTS BEFORE	PERCENT CHANGE IN NUMBER OF EVENTS AFTER					
	CONFIDENCE >/= 0.99		CONFIDENCE >/= 0.95		CONFIDENCE >/= 0.90	
	DECREASE	INCREASE	DECREASE	INCREASE	DECREASE	INCREASE
10	90.0	150.0	70.0	100.0	60.0	80.0
11	90.9	145.5	72.7	100.0	63.6	81.8
12	83.3	133.3	66.7	91.7	58.3	75.0
13	84.6	123.1	61.5	84.6	53.8	69.2
14	78.6	121.4	64.3	85.7	50.0	64.3
15	73.3	113.3	60.0	80.0	53.3	60.0
16	75.0	112.5	56.3	75.0	50.0	62.5
17	70.6	105.9	58.8	76.5	47.1	58.8
18	72.2	100.0	55.6	72.2	44.4	55.6
19	68.4	100.0	52.6	68.4	47.4	52.6
20	65.0	95.0	50.0	65.0	45.0	55.0
21	66.7	95.2	52.4	66.7	42.9	52.4
22	63.6	90.9	50.0	63.6	40.9	50.0
23	65.2	87.0	47.8	60.9	39.1	47.8
24	62.5	87.5	45.8	58.3	37.5	45.8
25	60.0	84.0	48.0	60.0	40.0	48.0
26	61.5	80.8	46.2	57.7	38.5	46.2
27	59.3	81.5	44.4	55.6	37.0	44.4
28	57.1	78.6	42.9	53.6	35.7	42.9
29	55.2	75.9	44.8	55.2	34.5	41.4

FIGURE 6 Revised decision criteria.

	PERCENT CHANGE IN NUMBER OF EVENTS AFTER					
	CONFIDENCE >/= 0.99		CONFIDENCE >/= 0.95		CONFIDENCE >/= 0.90	
EVENTS BEFORE	DECREASE	INCREASE	DECREASE	INCREASE	DECREASE	INCREASE
30	56.7	73.3	43.3	53.3	36.7	40.0
31	54.8	74.2	41.9	51.6	35.5	41.9
32	53.1	71.9	40.6	50.0	34.4	40.6
33	54.5	69.7	39.4	48.5	33.3	39.4
34	52.9	70.6	41.2	50.0	32.4	38.2
35	51.4	68.6	40.0	48.6	31.4	37.1
36	50.0	66.7	38.9	47.2	33.3	36.1
37	51.4	64.9	37.8	45.9	32.4	35.1
38	50.0	65.8	36.8	44.7	31.6	36.8
39	48.7	64.1	38.5	46.2	30.8	35.9
40	50.0	62.5	37.5	45.0	30.0	35.0
41	48.8	61.0	36.6	43.9	29.3	34.1
42	47.6	61.9	35.7	42.9	28.6	33.3
43	46.5	60.5	34.9	41.9	30.2	32.6
44	47.7	59.1	36.4	40.9	29.5	31.8
45	46.7	57.8	35.6	42.2	28.9	33.3
46	45.7	58.7	34.8	41.3	28.3	32.6
47	44.7	57.4	34.0	40.4	27.7	31.9
48	45.8	56.3	33.3	39.6	27.1	31.3
49	44.9	55.1	32.7	38.8	26.5	30.6
50	44.0	56.0	34.0	38.0	26.0	30.0
51	43.1	54.9	33.3	39.2	27.5	29.4
52	42.3	53.8	32.7	38.5	26.9	28.8
53	43.4	52.8	32.1	37.7	26.4	30.2
54	42.6	53.7	31.5	37.0	25.9	29.6
55	41.8	52.7	30.9	36.4	25.5	29.1
56	41.1	51.8	32.1	35.7	25.0	28.6
57	42.1	50.9	31.6	36.8	24.6	28.1
58	41.4	50.0	31.0	36.2	24.1	27.6
59	40.7	50.8	30.5	35.6	25.4	27.1
60	40.0	50.0	30.0	35.0	25.0	26.7
61	39.3	49.2	29.5	34.4	24.6	27.9
62	40.3	48.4	29.0	33.9	24.2	27.4
63	39.7	47.6	30.2	33.3	23.8	27.0
64	39.1	48.4	29.7	34.4	23.4	26.6
65	38.5	47.7	29.2	33.8	23.1	26.2
66	37.9	47.0	28.8	33.3	22.7	25.8
67	38.8	46.3	28.4	32.8	22.4	25.4
68	38.2	45.6	27.9	32.4	23.5	25.0
69	37.7	46.4	27.5	31.9	23.2	24.6
70	37.1	45.7	28.6	31.4	22.9	25.7
71	36.6	45.1	28.2	32.4	22.5	25.4
72	37.5	44.4	27.8	31.9	22.2	25.0
73	37.0	43.8	27.4	31.5	21.9	24.7
74	36.5	44.6	27.0	31.1	21.6	24.3
75	36.0	44.0	26.7	30.7	21.3	24.0
76	35.5	43.4	26.3	30.3	21.1	23.7
77	36.4	42.9	27.3	29.9	22.1	23.4
78	35.9	42.3	26.9	29.5	21.8	23.1
79	35.4	43.0	26.6	30.4	21.5	22.8
80	35.0	42.5	26.3	30.0	21.3	23.8
81	34.6	42.0	25.9	29.6	21.0	23.5
82	35.4	41.5	25.6	29.3	20.7	23.2
83	34.9	41.0	25.3	28.9	20.5	22.9
84	34.5	41.7	25.0	28.6	20.2	22.6
90	33.3	40.0	24.4	27.8	20.0	22.2
91	33.0	39.6	24.2	27.5	19.8	22.0
92	32.6	39.1	23.9	27.2	19.6	21.7
93	32.3	38.7	24.7	26.9	19.4	21.5
94	33.0	38.3	24.5	26.6	19.1	21.3
95	32.6	37.9	24.2	27.4	18.9	21.1
96	32.3	38.5	24.0	27.1	18.8	20.8
97	32.0	38.1	23.7	26.8	18.6	20.6
98	31.6	37.8	23.5	26.5	19.4	20.4
99	31.3	37.4	23.2	26.3	19.2	20.2
100	32.0	37.0	23.0	26.0	19.0	21.0
101	31.7	36.6	22.8	25.7	18.8	20.8
102	31.4	37.3	23.5	25.5	18.6	20.6
103	31.1	36.9	23.3	26.2	18.4	20.4
104	30.8	36.5	23.1	26.0	18.3	20.2
105	30.5	36.2	22.9	25.7	18.1	20.0
106	31.1	35.8	22.6	25.5	17.9	19.8

FIGURE 6 (continued)

	PERCENT CHANGE IN NUMBER OF EVENTS AFTER					
	CONFIDENCE >/= 0.99		CONFIDENCE >/= 0.95		CONFIDENCE >/= 0.90	
EVENTS BEFORE	DECREASE	INCREASE	DECREASE	INCREASE	DECREASE	INCREASE
107	30.8	35.5	22.4	25.2	17.8	19.6
108	30.6	36.1	22.2	25.0	17.6	19.4
109	30.3	35.8	22.0	24.8	18.3	19.3
110	30.0	35.5	22.7	24.5	18.2	19.1
111	29.7	35.1	22.5	24.3	18.0	18.9
112	30.4	34.8	22.3	25.0	17.9	19.6
113	30.1	34.5	22.1	24.8	17.7	19.5
114	29.8	34.2	21.9	24.6	17.5	19.3
115	29.6	34.8	21.7	24.3	17.4	19.1
116	29.3	34.5	21.6	24.1	17.2	19.0
117	29.1	34.2	21.4	23.9	17.1	18.8
118	29.7	33.9	21.2	23.7	16.9	18.6
119	29.4	33.6	21.0	23.5	16.8	18.5
120	29.2	33.3	21.7	23.3	17.5	18.3
121	28.9	33.9	21.5	24.0	17.4	18.2
122	28.7	33.6	21.3	23.8	17.2	18.0
123	28.5	33.3	21.1	23.6	17.1	17.9
124	28.2	33.1	21.0	23.4	16.9	18.5
125	28.8	32.8	20.8	23.2	16.8	18.4
126	28.6	32.5	20.6	23.0	16.7	18.3
127	28.3	32.3	20.5	22.8	16.5	18.1
128	28.1	32.8	20.3	22.7	16.4	18.0
129	27.9	32.6	20.9	22.5	16.3	17.8
130	27.7	32.3	20.8	22.3	16.2	17.7
131	27.5	32.1	20.6	22.9	16.0	17.6
132	28.0	31.8	20.5	22.7	15.9	17.4
133	27.8	31.6	20.3	22.6	16.5	17.3
134	27.6	31.3	20.1	22.4	16.4	17.2
135	27.4	31.9	20.0	22.2	16.3	17.0
136	27.2	31.6	19.9	22.1	16.2	17.6
137	27.0	31.4	19.7	21.9	16.1	17.5
138	26.8	31.2	19.6	21.7	15.9	17.4
139	27.3	30.9	20.1	21.6	15.8	17.3
140	27.1	30.7	20.0	21.4	15.7	17.1
141	27.0	30.5	19.9	22.0	15.6	17.0
142	26.8	31.0	19.7	21.8	15.5	16.9
143	26.6	30.8	19.6	21.7	15.4	16.8
144	26.4	30.6	19.4	21.5	15.3	16.7
145	26.2	30.3	19.3	21.4	15.2	16.6
146	26.7	30.1	19.2	21.2	15.8	16.4
147	26.5	29.9	19.0	21.1	15.6	16.3
148	26.4	29.7	18.9	20.9	15.5	16.2
149	26.2	30.2	19.5	20.8	15.4	16.1
150	26.0	30.0	19.3	20.7	15.3	16.7
151	25.8	29.8	19.2	21.2	15.2	16.6
152	25.7	29.6	19.1	21.1	15.1	16.4
153	25.5	29.4	19.0	20.9	15.0	16.3
154	26.0	29.2	18.8	20.8	14.9	16.2
155	25.8	29.0	18.7	20.6	14.8	16.1
156	25.6	28.8	18.6	20.5	14.7	16.0
157	25.5	29.3	18.5	20.4	14.6	15.9
158	25.3	29.1	18.4	20.3	14.6	15.8
159	25.2	28.9	18.2	20.1	15.1	15.7
160	25.0	28.8	18.8	20.0	15.0	15.6
161	25.5	28.6	18.6	19.9	14.9	15.5
162	25.3	28.4	18.5	20.4	14.8	15.4
163	25.2	28.2	18.4	20.2	14.7	16.0
164	25.0	28.0	18.3	20.1	14.6	15.9
165	24.8	28.5	18.2	20.0	14.5	15.8
166	24.7	28.3	18.1	19.9	14.5	15.7
167	24.6	28.1	18.0	19.8	14.4	15.6
168	24.4	28.0	17.9	19.6	14.3	15.5
169	24.9	27.8	17.8	19.5	14.2	15.4
170	24.7	27.6	17.6	19.4	14.1	15.3
171	24.6	27.5	18.1	19.3	14.0	15.2
172	24.4	27.3	18.0	19.2	14.0	15.1
173	24.3	27.7	17.9	19.7	13.9	15.0
174	24.1	27.6	17.8	19.5	14.4	14.9
175	24.0	27.4	17.7	19.4	14.3	14.9
176	23.9	27.3	17.6	19.3	14.2	14.8
177	24.3	27.1	17.5	19.2	14.1	14.7
178	24.2	27.0	17.4	19.1	14.0	15.2
179	24.0	26.8	17.3	19.0	14.0	15.1

FIGURE 6 (continued)

FIGURE 6 (continued)

PERCENT CHANGE IN NUMBER OF EVENTS AFTER

EVENTS BEFORE	CONFIDENCE >/= 0.99		CONFIDENCE >/= 0.95		CONFIDENCE >/= 0.90	
	DECREASE	INCREASE	DECREASE	INCREASE	DECREASE	INCREASE
180	23.9	26.7	17.2	18.9	13.9	15.0
181	23.8	27.1	17.1	18.8	13.8	14.9
182	23.6	26.9	17.6	18.7	13.7	14.8
183	23.5	26.8	17.5	18.6	13.7	14.8
184	23.4	26.6	17.4	18.5	13.6	14.7
185	23.8	26.5	17.3	18.9	13.5	14.6
186	23.7	25.8	17.2	18.8	13.4	14.5
187	23.5	26.2	17.1	18.7	13.4	14.4
188	23.4	26.1	17.0	18.6	13.8	14.4
189	23.3	26.5	21.2	18.5	13.8	14.3
190	23.2	26.3	16.8	18.4	13.7	14.2
191	23.0	26.2	16.8	18.3	13.6	14.1
192	22.9	26.0	16.7	18.2	13.5	14.1
193	23.3	25.9	16.6	18.1	13.5	14.5
194	23.2	25.8	17.0	18.0	13.4	14.4
195	23.1	25.6	16.9	17.9	13.3	14.4
196	23.0	25.5	16.8	17.9	13.3	14.3
197	22.8	25.4	16.8	18.3	13.2	14.2
198	22.7	25.8	16.7	18.2	13.1	14.1
199	22.6	25.6	16.6	18.1	13.1	14.1
200	22.5	25.5	16.5	18.0	13.0	14.0
201	22.4	25.4	16.4	17.9	12.9	13.9
202	22.8	25.2	16.3	17.8	12.9	13.9
203	22.7	25.1	16.3	17.7	12.8	13.8
204	22.5	25.0	16.2	17.6	13.2	13.7
205	22.4	24.9	16.1	17.6	13.2	13.7
206	22.3	25.2	16.5	17.5	13.1	13.6
207	22.2	25.1	16.4	17.4	13.0	13.5
208	22.1	25.0	16.3	17.3	13.0	13.5
209	22.0	24.9	16.3	17.7	12.9	13.9

THIS TABLE APPLIES TO EVENTS THAT ARE POISSON DISTRIBUTED. EACH CONFIDENCE LEVEL REPRESENTS THE ONE-TAILED PROBABILITY THAT PERCENT CHANGES AS EXTREME AS THOSE LISTED WOULD NOT BE EXCEEDED DUE JUST TO CHANCE.

University of Toronto. Although both the format and the derivation are different from that used for the tables presented in this paper, where a comparison is possible the agreement appears to be exact. I highly recommend these tables.

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