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SIMULATION STUDY OF THE POWER OF THE KOLMOGOROV-SMIRNOV AND Z TESTS FOR THE EXPONENTIAL DISTRIBUTION

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INTRODUCTION

The assumption that the input source or calling population is a Poisson process is common to many operations research models such as waiting lines, inventory systems, and maintenance schedules. When this assumption cannot be supported, computational techniques assuming Poisson input are inapplicable and the scope of the operations analyst's study of the system may be severely limited.

Epstein[1] gave a fairly comprehensive review of methods for testing the validity of the assumption that the underlying distribution of life is exponential. Reinmuth[2] suggested a "simple statistical test for detection of a Poisson input source" based on the fact that events generated by such a source are uniformly distributed over time, i.e., the probability that an event will occur within any given interval of time remains constant. This particular test was among those reviewed earlier by Epstein. Scheuer and Trueman[3] discussed several methods of testing including Reinmuth's test and also the modified Kolmogorov-Smirnov test described by Lilliefors[4] for the exponential distribution with mean unknown.

Any of these methods would suffice for many applications provided sufficient data were available for testing purposes. Since valid data may be extremely limited for many practical situations[5], a computer simulation study was carried out to compare the power of the Reinmuth or Z test with that of the Kolmogorov-Smirnov or KS test for the exponential distribution against a wide range of alternatives.

SIMULATION PROCEDURE

In order to carry out the study under conditions which would be applicable to a wide range of practical problems, two classes of alternative distributions were used. The first was generated by substituting uniformly distributed random numbers for the cumulative distribution function of the two parameter Weibull and solving for the inverse. By varying the constant for the shape parameter, the nature of the resulting distribution of times between events could be varied widely for different cases. Thus, for a shape parameter of 3.3 the distribution is approximately normal, whereas for a shape parameter of 1.0, the distribution is exponential.

A second class of alternatives was sought for which the nature of the distribution remained constant but the rate parameter changed gradually as a function of time. Such a class of distributions should be useful for representing the daily or seasonal variations in the rates of customer arrivals at serving lines, etc. A cursory survey of the simulation literature was carried out but failed to suggest an algorithm for generation of data with a changing rate parameter. However, after some deliberation, it was noted that times between events could be generated for any distribution function, these values could be laid out in sequence on a time line starting at some appropriate point to give times of occurrence of successive events, these times could in turn be transformed by use of some appropriate mathematical function, and finally a set of transformed times between events could be obtained by subtraction. For the present study, the exponential distribution was selected, the starting point was taken to be time equal to one, and the transformation was effected by simply raising the times of occurrence to some exponent in the range of 0.4 to 2.0. Values for this exponent of less than unity gave decreasing times between successive events whereas values greater than unity gave increasing times. Times generated in this manner were considered to represent a Poisson type process with a gradually changing rate parameter.

A simulation case was considered to consist of all data generated for some specific value of either the shape parameter of the Weibull distribution or the exponent used to generate a Poisson process with changing rate parameter. Each case consisted of 5000 replicate runs and provided data for a number of different sample sizes. To minimize the effects of sampling variations, the random number generator was set to the same initial value at the beginning of each simulation case and was not reset until the next case. Different initial values were used for the two classes of alternative distributions.

ANALYTICAL PROCEDURES

For the KS test, the test statistic given by Mann, Schafer, and Singpurwalla[6] was calculated for each sample size of each simulation run and compared with the critical values given by Lilliefors.

For the Z test, the test duration is normally some specified period of time rather than some specified number of events. However, for this study, the duration of each portion of each simulation run was determined by the time at which the last event occurred plus a correction amounting to one half the average time between events for that run. Z values were calculated in accordance with Reinmuth's procedure and compared with the critical values of the normal distribution.

VALIDATION OF SIMULATION RESULTS

Lilliefors gave simulation results for the power of the KS test when the alternative distribution was log normal. To obtain an overall validation of the simulation procedures used in this study, data for the log normal distribution was generated using the function suggested by Hahn and Shapiro.[7] The results for the KS test are in good agreement with those of Lilliefors as shown below.

Sample Size	Critical Level	Probability of Rejecting Hypothesis*	
		Lilliefors	This Study
10	.01	.023	.037
10	.05	.082	.089
20	.01	.046	.046
20	.05	.113	.136
50	.01	.085	.096
50	.05	.215	.255

*Both studies based on 1000 simulation runs.

RESULTS

Tables 1 and 2 give the results for the power of the KS test against alternative distributions consisting of the two parameter Weibull with shape parameters ranging from 0.5 to 4.0. Note that for a shape parameter of 1.0, the distribution is actually exponential and the results are in excellent agreement with the expected values of 1 and 5 percent for sample sizes up to around 70. For larger sample sizes, the results exceed the expected values by amounts which appear to be significant. Although this could indicate a bias in the random number generator, it could also indicate that the Lilliefors[4] approximation method for calculating critical values is slightly biased for the larger sample sizes. Since the difference between the observed and expected values was small, no attempt was made to determine the exact cause.

Results for shape parameters other than 1.0 indicate that the KS test is quite powerful for this class of alternative distributions with only seven instances for which the power of the test was less than 80 percent at the 5 percent level of significance. Note that for a shape factor of 3.3 for which the Weibull distribution approximates a normal distribution, the power of the test was 94.3 percent for the 5 percent level of significance and a sample size of only 10.

Since Reinmuth's Z test is dependent on a changing rate parameter rather than the nature of the distribution function, it would not be expected to reject the null hypothesis for this class of alternative distributions. Values determined for the power of the Z test for a few simulation cases served to confirm this expectation and are not presented.

Results for the KS test are given in Tables 3 and 4 for the second class of alternative distributions. Note that when the exponent used for transformation is equal to one, no transformation takes place and the resulting distribution is exponential. Inspection indicates that the KS data for this case are, as expected, very similar to those given in Tables 1 and 2 for the Weibull distribution with shape parameter equal to one.

Results for the Z test are given in Tables 5 and 6 for this same class of alternative distributions. Values for the power of the test when the exponent was one are somewhat higher than the expected values for the smaller sample sizes. To determine if this anomaly was due to the approximation method of determining test duration used for this study, a number of additional cases were simulated using an exponent of one and varying the correction added to the time of occurrence of the last event. The results, not shown, were sensitive to this variable and indicated that a correction of approximately 0.4 gave results in close agreement with the expected values for sample sizes of ten.

Inspection of the results in Tables 3 through 6 for exponents other than one indicates that the Z test is consistently more powerful than the KS test against this class of alternatives with differences greater than 70 percentage points being determined for some cases.

CONCLUSIONS

For the class of alternative distributions represented by the two parameter Weibull, the KS test for the exponential distribution is quite powerful whereas the Z test is worthless. On the other hand, for the class of alternatives with changing rate parameters, the Z test is consistently more powerful than the KS test with differences in excess of 70 percentage points for some cases. It is therefore concluded that both tests should be used for applications for which detailed knowledge regarding the possible classes of alternative distributions is lacking.

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TABLE 1. POWER OF THE KS TEST AT 5 PERCENT LEVEL OF SIGNIFICANCE WHEN THE ALTERNATIVE DISTRIBUTION WAS THE TWO PARAMETER WEIBULL

Values in the body of the table represent probabilities (in percent) of rejecting the null hypothesis.

Sample Size	Shape Parameter for Weibull Distribution								
	0.5	1.0	1.5	2.0	2.5	3.0	3.3	3.5	4.0
10	58.1	5.0	19.3	49.2	74.7	89.6	94.3	95.7	98.5
20	86.0	4.8	40.4	85.1	98.2	99.9	100.0	100.0	100.0
30	97.1	5.1	56.1	96.0	99.9	100.0	100.0	100.0	100.0
40	99.5	5.0	69.7	99.4	100.0	100.0	100.0	100.0	100.0
50	99.8	5.2	80.9	99.9	100.0				
60	100.0	5.3	87.8	100.0	100.0				
70	100.0	5.5	93.0	100.0	100.0				
80	100.0	5.7	95.6	100.0	100.0				
90	100.0	5.8	97.6	100.0	100.0				
100	100.0	5.7	98.7	100.0					
110	100.0	6.0	99.4	100.0					
120	100.0	6.1	99.8	100.0					
130	100.0	6.4	99.9	100.0					
140	100.0	6.0	100.0						

TABLE 2. POWER OF THE KS TEST AT 1 PERCENT LEVEL OF SIGNIFICANCE WHEN THE ALTERNATIVE DISTRIBUTION WAS THE TWO PARAMETER WEIBULL

Values in the body of the table represent probabilities (in percent) of rejecting the null hypothesis.

Sample Size	Shape Parameter for Weibull Distribution								
	0.5	1.0	1.5	2.0	2.5	3.0	3.3	3.5	4.0
10	39.7	1.1	6.1	20.7	42.8	65.0	74.1	79.2	89.0
20	72.9	1.1	15.5	58.1	88.3	98.0	99.5	99.7	100.0
30	90.9	1.0	27.3	84.8	98.6	100.0	100.0	100.0	100.0
40	97.3	0.9	42.1	95.1	99.9	100.0	100.0	100.0	100.0
50	99.4	1.3	54.7	98.9	100.0	100.0	100.0	100.0	100.0
60	99.8	1.4	67.0	99.8	100.0				
70	100.0	1.3	77.4	100.0	100.0				
80	100.0	1.1	84.4	100.0	100.0				
90	100.0	1.2	89.6	100.0					
100	100.0	1.3	93.2	100.0					
110	100.0	1.6	95.5	100.0					
120	100.0	1.4	97.3	100.0					
130	100.0	1.4	98.7	100.0					
140	100.0	1.3	98.9	100.0					

TABLE 3. POWER OF THE KS TEST AT 5 PERCENT LEVEL OF SIGNIFICANCE WHEN THE ALTERNATIVE DISTRIBUTION WAS A POISSON PROCESS WITH CHANGING RATE PARAMETER

Values in the body of the table represent probabilities (in percent) of rejecting the null hypothesis.

Sample Size	Exponent Used to Obtain a Changing Rate Process																
	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
10	6.9	5.6	5.1	5.3	4.8	5.1	5.0	4.6	5.3	5.9	6.7	6.6	7.9	9.3	10.9	12.8	14.9
20	13.7	8.8	6.8	5.1	4.8	4.6	4.6	4.7	5.2	5.7	6.9	8.0	10.2	14.2	16.3	19.6	23.7
30	22.8	12.4	8.0	6.0	4.8	4.7	4.6	5.0	5.5	6.1	7.5	9.5	12.1	16.5	21.8	27.3	32.8
40	31.9	16.5	9.4	6.1	5.6	5.2	5.0	5.2	6.0	7.0	9.1	11.3	15.5	21.3	27.3	33.6	41.1
50	41.3	21.4	11.1	6.4	5.1	5.3	5.0	5.2	5.8	7.7	10.1	13.6	18.7	24.9	32.8	40.3	48.8
60	51.2	27.0	12.9	6.9	6.0	5.1	4.9	5.4	5.9	7.7	10.5	15.2	20.5	27.9	37.3	46.6	55.8
70	60.8	32.0	15.0	7.7	5.8	5.1	5.3	5.4	6.4	8.3	11.1	16.4	22.8	31.8	42.5	51.9	62.6
80	68.5	37.1	16.4	8.3	6.0	5.3	5.3	5.7	6.7	8.5	11.7	17.5	25.3	35.4	46.5	57.5	67.9
90	75.6	42.1	18.6	9.0	5.9	5.4	5.1	5.3	6.6	8.8	12.7	19.7	28.7	40.2	50.8	62.7	72.6
100	81.6	47.7	20.8	10.2	6.7	6.0	5.4	5.9	6.8	9.2	13.8	20.5	29.9	43.0	54.7	66.5	76.9
110			23.6	10.3	6.7	5.7	5.9	5.7	7.1	10.0	14.7	22.2	32.4	46.2			
120			25.5	10.8	7.1	6.0	5.9	5.9	7.4	9.7	14.8	23.9	35.0	48.3			
130			27.7	11.9	7.5	6.0	6.1	6.5	7.6	10.5	15.9	25.4	37.8				
140			29.6	12.3	7.7	6.1	6.0	6.7	7.5	10.2	16.4	26.6	39.9				
150			32.5	-	7.7	6.3	6.3	6.7	7.9	11.1	17.5	-	-				
160			34.4	-	7.8	6.1	6.4	6.8	8.3	11.0	18.1	-	-				
170			-	-	7.4	6.2	6.3	6.6	8.3	11.6	18.8	-	-				
180			-	-	7.2	5.8	6.0	6.8	8.3	11.6	20.0	-	-				
190			-	-	7.6	5.8	5.7	6.7	8.1	11.9	20.4	-	-				
200			-	-	8.1	6.1	5.8	6.6	8.3	11.9	21.2	-	-				

TABLE 4. POWER OF THE KS TEST AT 1 PERCENT LEVEL OF SIGNIFICANCE WHEN THE ALTERNATIVE DISTRIBUTION WAS A POISSON PROCESS WITH CHANGING RATE PARAMETER

Values in the body of the table represent probabilities (in percent) of rejecting the null hypothesis.

Sample Size	Exponent Used to Obtain a Changing Rate Process																
	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
10	1.8	1.3	1.0	1.1	1.0	1.0	1.0	1.0	1.1	1.2	1.6	2.4	2.7	3.3	3.9	4.8	6.0
20	4.6	2.7	1.6	1.1	0.9	0.9	1.0	0.9	0.9	1.2	1.6	2.4	3.0	4.8	6.4	8.0	10.2
30	9.1	4.3	1.9	1.2	1.0	1.1	1.0	1.2	1.4	1.6	2.5	3.3	4.7	6.5	9.5	12.6	16.8
40	14.5	6.7	2.8	1.5	0.9	0.9	1.3	1.3	1.2	1.9	3.0	4.1	5.9	9.0	12.9	17.8	23.1
50	21.6	8.5	3.6	1.7	1.0	0.7	1.0	1.1	1.6	2.1	3.4	4.8	7.2	10.9	16.7	23.4	30.5
60	28.9	11.0	4.0	1.9	1.1	0.9	0.9	1.1	1.4	2.2	3.3	5.5	9.1	13.4	20.8	27.4	35.8
70	37.3	14.8	5.1	2.0	1.2	1.1	0.9	1.2	1.3	2.0	3.6	6.3	10.4	15.8	23.3	32.4	41.7
80	45.6	18.1	5.9	2.4	1.3	0.9	1.1	1.0	1.4	2.3	4.2	6.7	11.5	18.5	27.0	36.2	47.0
90	53.8	22.0	6.9	2.7	1.2	1.2	1.1	1.2	1.5	2.6	4.5	7.8	13.2	20.8	31.1	41.9	53.2
100	61.2	25.8	7.8	2.7	1.3	1.0	1.3	1.5	1.9	2.9	5.2	8.7	14.6	23.1	34.4	45.9	57.9
110			9.2	3.2	1.7	1.5	1.4	1.6	2.0	2.9	5.9	9.9	16.3	26.5			
120			10.0	3.4	1.7	1.2	1.3	1.5	2.2	3.1	6.0	10.8	18.4	28.3			
130			11.4	3.7	1.9	1.6	1.5	1.5	2.0	3.3	6.3	11.9	20.1				
140			12.3	4.2	2.0	1.3	1.4	1.4	2.0	3.6	6.8	12.4	21.2				
150			13.6	-	2.0	1.1	1.5	1.6	2.0	3.8	7.2	-	-				
160			15.4	-	2.0	1.3	1.3	1.7	2.2	4.2	7.5	-	-				
170			-	-	2.2	1.3	1.4	1.8	2.3	4.2	8.1	-	-				
180			-	-	2.3	1.2	1.3	1.4	2.2	4.2	8.3	-	-				
190			-	-	2.4	1.4	1.5	1.5	2.4	4.2	8.8	-	-				
200			-	-	2.3	1.5	1.6	1.6	2.4	4.5	8.9	-	-				

TABLE 5. POWER OF THE Z TEST AT 5 PERCENT LEVEL OF SIGNIFICANCE WHEN THE ALTERNATIVE DISTRIBUTION WAS A POISSON PROCESS WITH CHANGING RATE PARAMETER

Values in the body of the table represent probabilities (in percent) of rejecting the null hypothesis.

Sample Size	Exponent Used to Obtain a Changing Rate Process																
	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
10	43.7	32.0	31.9	22.1	15.1	10.1	7.4	5.5	4.6	4.2	4.9	5.7	7.2	9.3	17.5	21.2	24.7
20	80.8	62.9	51.5	32.9	17.9	10.3	5.9	4.6	5.9	8.3	12.1	17.9	24.3	31.8	45.3	52.7	59.7
30	95.5	82.7	67.0	42.6	23.0	11.0	5.6	4.8	7.4	13.3	21.7	31.0	42.0	52.2	68.8	76.6	82.2
40	99.2	93.3	78.8	52.4	28.6	12.2	5.2	5.1	9.8	19.4	30.3	45.0	58.1	68.9	82.5	88.5	92.1
50	99.9	97.3	87.4	61.0	32.6	13.1	6.1	6.4	13.6	25.0	40.4	56.8	69.5	79.9	89.9	93.8	96.6
60	100.0	99.1	92.1	68.8	37.0	14.0	5.4	7.1	15.9	31.2	48.7	65.8	79.0	87.5	94.4	97.1	98.5
70	100.0	99.7	95.7	76.7	40.9	15.1	5.2	7.1	18.6	36.9	56.8	73.6	85.8	92.4	97.5	98.7	99.3
80	100.0	99.9	97.8	81.3	45.8	16.1	5.1	8.2	21.6	43.0	63.3	79.5	89.9	94.9	98.4	99.4	99.8
90	100.0	100.0	98.7	84.6	47.2	16.8	5.5	9.0	25.7	49.0	70.7	84.8	93.2	96.9	99.2	99.7	99.9
100	100.0	100.0	99.4	88.1	50.9	17.4	5.5	10.3	29.3	54.8	75.7	89.0	95.6	98.5	99.6	99.9	100.0
110			99.7	91.2	54.4	18.9	6.0	11.3	31.9	58.3	79.6	91.7	96.9	98.9			
120			99.9	93.3	59.3	19.4	5.2	12.1	34.3	61.9	83.4	93.7	98.1	99.4			
130			99.9	95.1	62.3	21.5	5.4	12.7	36.9	65.9	86.3	95.8	98.9	-			
140			100.0	96.3	65.4	21.7	5.3	12.7	39.5	69.6	88.4	96.8	99.3	-			
150			100.0	-	68.2	23.1	5.0	13.7	42.3	72.6	90.8	-	-	-			
160			100.0	-	71.2	24.0	5.4	14.7	45.5	75.5	92.6	-	-	-			
170			-	-	73.2	24.3	5.5	15.7	48.0	79.1	94.1	-	-	-			
180			-	-	76.8	26.3	5.3	16.3	49.7	81.0	95.3	-	-	-			
190			-	-	77.5	27.4	5.2	17.6	51.5	83.2	96.6	-	-	-			
200			-	-	79.6	28.2	5.0	19.0	54.3	85.0	97.1	-	-	-			

TABLE 6. POWER OF THE Z TEST AT 1 PERCENT LEVEL OF SIGNIFICANCE WHEN THE ALTERNATIVE DISTRIBUTION WAS A POISSON PROCESS WITH CHANGING RATE PARAMETER

Values in the body of the table represent probabilities (in percent) of rejecting the null hypothesis.

Sample Size	Exponent Used to Obtain a Changing Rate Process																
	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
10	17.7	10.5	11.5	6.6	4.4	2.9	1.6	1.0	0.6	0.6	0.6	0.9	1.5	1.7	5.1	6.7	8.4
20	55.6	34.3	26.0	13.0	5.9	2.6	1.3	0.8	0.9	1.8	3.6	5.9	8.7	14.2	23.1	29.1	35.3
30	83.3	58.4	40.5	18.8	7.9	2.8	0.9	0.9	1.7	3.9	7.8	13.1	20.3	29.2	45.1	53.8	62.0
40	95.5	77.7	53.3	26.8	10.1	3.4	1.2	1.1	2.7	6.5	13.3	23.1	33.6	45.2	63.3	72.7	79.7
50	98.8	89.8	66.3	34.8	13.2	4.3	1.1	1.3	4.5	10.3	19.7	32.6	47.3	59.2	74.7	82.9	89.1
60	99.8	95.1	77.4	43.0	16.0	4.5	1.3	1.3	5.4	13.7	26.8	41.6	57.8	71.1	83.8	90.6	94.5
70	100.0	98.2	85.5	51.6	18.7	4.7	1.1	1.7	6.1	17.0	33.2	50.4	67.0	79.7	90.8	95.3	97.7
80	100.0	99.4	90.5	59.1	21.6	5.1	1.3	2.1	7.8	21.2	40.3	58.7	75.2	86.2	94.6	97.3	98.7
90	100.0	99.8	94.0	65.5	24.5	5.5	1.1	2.3	9.9	26.3	47.9	67.2	81.7	90.8	96.8	98.3	99.4
100	100.0	99.9	96.1	70.7	26.9	6.0	1.0	2.6	12.4	31.6	55.0	72.3	87.2	94.1	98.1	99.3	99.8
110			97.6	75.3	30.4	7.0	1.2	3.4	13.8	35.4	59.4	78.7	90.5	95.9			
120			98.9	80.1	34.4	7.0	1.1	3.4	15.6	38.9	63.6	83.2	93.2	97.3			
130			99.4	84.0	37.0	7.5	1.3	3.7	17.8	42.3	69.1	86.8	95.7	-			
140			99.5	86.8	39.9	8.4	1.1	3.9	18.8	47.1	73.3	89.4	96.9	-			
150			99.8	-	43.0	8.5	1.0	4.2	20.7	50.7	77.0	-	-	-			
160			99.8	-	46.1	8.7	1.0	4.3	22.9	54.6	80.1	-	-	-			
170			-	-	49.0	9.7	1.2	4.9	25.6	58.0	83.4	-	-	-			
180			-	-	52.8	10.2	1.2	5.3	26.6	60.6	85.8	-	-	-			
190			-	-	55.7	10.0	1.1	5.9	29.3	63.8	88.6	-	-	-			
200			-	-	57.9	10.7	1.0	6.2	31.2	67.0	91.0	-	-	-			

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16. Abstract

Simulation tests were carried out to compare the power of the Kolmogorov-Smirnov and Z tests for the exponential distribution against a wide range of alternative distributions. The results indicate that both tests should be used for applications for which detailed knowledge regarding the possible classes of alternative distributions is lacking.

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