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Research Article

Designing double sampling plans within supply chain contract – A simulation study utilizing normal and lognormal distributions

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ABSTRACT

The present study proposes the designing of double sampling plans integrated with Supply Chain Contract through the simulation model based on normal and lognormal distributions. These plans are constructed through a simulation model implemented with GoldSim(14.0). The plan parameters of the proposed plans viz., the sample sizes and the acceptance numbers are determined. For various quality-related parameters, tables were provided for the selection of double sampling plans according to the required proportion defective. This paper considers the certain distribution characterized by the normal and the lognormal distributions for the double sampling plans within supply chain contract.

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INTRODUCTION

Acceptance sampling plans have become instrumental in achieving the goal of high quality of the products. An acceptance sampling plan is a method of inspection employed to make the decision whether to accept or reject a particular batch of materials. The primary challenge within an acceptance sampling plan pertains to the amount of time dedicated to testing the batch. In these plans, the acceptance or rejection of a lot of products is decided based on the inspection of random samples taken from the lot. Aslam [1] developed the Rayleigh distribution based on double sampling depending on truncated life tests. Aslam et al. [2, 3] proposed double sampling plans based on truncated life tests for the Weibull distribution and general life distribution.

A double sampling plan for generalized log-logistic distribution with known shape parameters have been developed by Aslam and Jun [4]. Rao [5, 6] considered double sampling plans for the Marshall–Olkin extended exponential and Marshall–Olkin extended Lomax distributions depending on average life time of the truncated life testing data. Aslam et al. [7] discussed double-acceptance sampling plans for Burr type-XII distributionunder the truncated life tests. In generalized exponential distribution, Ramaswamy and Anburajan [8] presented double acceptance sampling based on truncated life-tests. Gui [9] has developed a double-acceptance sampling plan for time-truncated life-tests

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based on Maxwell distribution. Malathi and Muthulakshmi [10] developed a zero-one double-acceptance sampling plan based on Marshall–Olkin extended exponential distribution for truncated life tests. Tripathi et al. [11] developed an application of time-truncated single-acceptance sampling plan based on generalized half-normal distribution. Tripathi et al. [12] studied doubleand group-acceptance sampling plans for truncated life test based on inverse log-logistic distribution.

Supply chain contract (SCC) is a legally binding agreement between two or more parties.This paper examines the incentive effect of the acceptance sampling plan on the quality delivered by a risk averse, utility maximizing supplier. We assume that the supplier has control over quality, and that the supplier delivers to the customer a quality level that maximizes the supplier›s expected utility. An expected utility framework is appropriate because, from the supplier›s point of view, acceptance sampling is a lottery in which a ‹win› is the acceptance of a submitted lot and a ‹loss› is the rejection of a submitted lot. The supplier can increase the probability of a win by improving the quality of the lots delivered to the customer. However, as the supplier improves the delivered quality, costs increase and the supplier›s payoff from the win declines. Changes in the payoff change not only the expected return to the supplier, but also the supplier›s returns, an important consideration for the risk-averse decision maker.

Supply chain contracting has significantly contributed to the broader application of economic modeling in production research, particularly when updated information is available. Cachon [13] and Tsay and Agrawal [14] categorized the single-price and two-price contracts. Several authors have studied various contracts with price mechanisms. Choi [15] examined fixed-fee contracts, while Cachon and Swinney [16, 17] investigated demand information updating within the quick response strategy using wholesale price contracts. Keser and Paleologo [18] along with Loch and Wu [19] focused on wholesale price contracts. Gopal [20] conducted a study on vendor preferences for contract types in offshore software projects, focusing on the choice between fixed-price and time-and-material contracts. Starbird [21] studied the influence of rewards, penalties and inspection policies on the behavior of an expected cost-minimizing supplier. RaviSankar and Sinthiya [22] constructed a simulation model by employing the Weibull distribution. Vafadarnikjoo et al. [23] proposed a framework for evaluating five barriers in a manufacturing company›s adoption of blockchain technology: transaction-level uncertainties (B1), usage in the underground economy (B2), scalability challenges (B3), privacy risks (B4), and managerial commitment (B5). Their study employed the N-AHP method to assess and prioritize these barriers based on their importance within the manufacturing context. Additionally, Wang et al. [24] constructed a neutrosophic decision-making matrix considering high uncertainty to integrate evaluation information effectively. This paper proposes the development of a simulation model for manufacturing industries that integrates double sampling plans with a supply chain contract, utilizing normal and lognormal distributions.

The notations used in this study are

n_1 : *Size of First Sample*
n_2 : *Size of Second Sample*
N : *Lot Size*
C : *Total Cost*
c_1 : *Acceptance Number from First Sample*
c_2 : *Acceptance Number from both Samples*
d_1 : *Defectives found in the First Sample*
d_2 : *Defectives found in the Second Sample*
$t(q)$: *Target Quality*
$m(q)$: *Mean Quality*
R_i : *Reward*
D_i : *Demand*
P_i : *Penalty*
$DSP(n, c_1, c_2)$: *Double Sampling Plan with* $n_1=n_2=n$ *and* c_1, c_2

RESEARCH METHODOLOGY

The software (GoldSim14.0) is used to develop a simulation model for the double sampling plans used in supply chain contracts. Ravi Sankar and Sinthiya [20] constructed the model for supply chain contract integrated with Double Sampling Plan (DSP) based on Weibull distribution using Goldsim software (14.0). This paper presents the development of a simulation model for SSC integrated with DSP based on the normal and lognormal distributions. (Fig. 1) The acceptance numbers, sample sizes, lot size and total cost are determined by the models illustrated in Figure 2 and Figure 3 by minimizing the total cost.

Double Sampling Plan (DSP) and its Probability of Acceptance

Let us consider an experimental situation where lifetimes of the test units follow normal distribution and the specified mean lifetime of the units claimed by a producer bem_0. It is interesting to make an inference about the acceptance or rejection of the proposed lot based on the criterion that the actual mean lifetime, m, of the units is larger than the prescribed lifetime m_0. In order to find out the observed mean lifetime, the experiment is run for $t_0=a.m_0$ units of time, where $m_0$is the mean lifetime. The procedure for DSP(n_1, n_2, c_1, c_2) are discussed in step by step:

Step 1: Select a random sample of size n_1 from the lot of size N.

Step 2: Count the number of defectives (d_1) in the first sample.

Step 3: If $d_1 \leq c_1$, accept the lot.

Step 4: If $d_1 > c_2$, reject the lot and replace the defective items with good items using 100% inspection.

Step 5: If $c_1 < d_1 \leq c_2$, select the second random sample of size $n_2$from the same lot.

Step 6: Count the number of defectives (d_2) found in the second sample.

Step 7: If $d_1+d_2 \leq c_2$, accept the lot; otherwise reject the lot and replace the defective items with good items using 100% inspection.

The probability of acceptance for DSP(n_1,n_2,c_1,c_2) is given in equation 1.

$$P_a(p) = \sum_{i=0}^{c_1} \frac{e^{-n_1 p}(n_1 p)^{x_i}}{x_i!} + \left[\sum_{j=c_1+1}^{c_2} \frac{e^{-n_1 p}(n_1 p)^{x_j}}{x_j!} \left\{\sum_{i=0}^{c_2-j} \frac{e^{-n_2 p}(n_2 p)^{x_i}}{x_i!}\right\}\right] \quad (1)$$

where $p = F_X(x)$, p is the proportion of defectives. For various combinations of target quality and mean quality-related values, the manufacturer aims to ensure that the product is not rejected, while the consumer seeks to reject products that do not meet the desired quality level.

The script used to calculate $P_a(p)$ for various 'p' values is given in Annexure 1. In the script, it is assumed that the first and second sample sizes are equal. ie., $n_1 = n_2 = n$and the plan is denoted by $DSP(n, c_1, c_2)$. The simulation model for the process of supply chain contracts is developed and presented in Figure 1.

The GoldSim elements and named elements used in the simulation models presented in Figure 1, Figure 2 and Figure 3 are listed in Table 1.

Developing Normal Distribution Based Simulation Model for Integrating DSP with SCC

Let the lifetime of a product follows the normal distribution with the probability density function

$$f(x, \mu, \sigma^2) = \frac{1}{\sigma\sqrt{2\pi}} exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) \; x \geq 0 \text{ and } \mu, \sigma > 0 \quad (2)$$

Its cumulative distribution function (cdf) is given by

$$F_X(x) = \Phi\left(\frac{x-\mu}{\sigma}\right) \quad (3)$$

The DSP (normal distribution) with SCC is developed and presented in the Figure 2.

Developing Lognormal Distribution Based Simulation Model for Integrating DSP with SCC

The lognormal distribution is defined by two parameters: the mean (μ) and the standard deviation (σ) of the natural logarithm of the random variable. If $ln(X) \sim N(\mu, \sigma^2)$ then probability density function of a lognormal distribution is expressed as

$$f(x, \mu, \sigma^2) = \frac{1}{x\sigma\sqrt{2\pi}} exp\left(-\frac{(ln\, x-\mu)^2}{2\sigma^2}\right) \quad (4)$$

The cumulative distribution function of the lognormal distribution is defined as

$$F_X(x) = \Phi\left(\frac{(ln\, x)-\mu}{\sigma}\right) \quad (5)$$

whereΦ is the cumulative distribution function of $N(0,1)$.

A simulation model for integrating DSP (based on lognormal distribution) with SCC is developed using the GoldSim Software and is presented in the Figure 3.

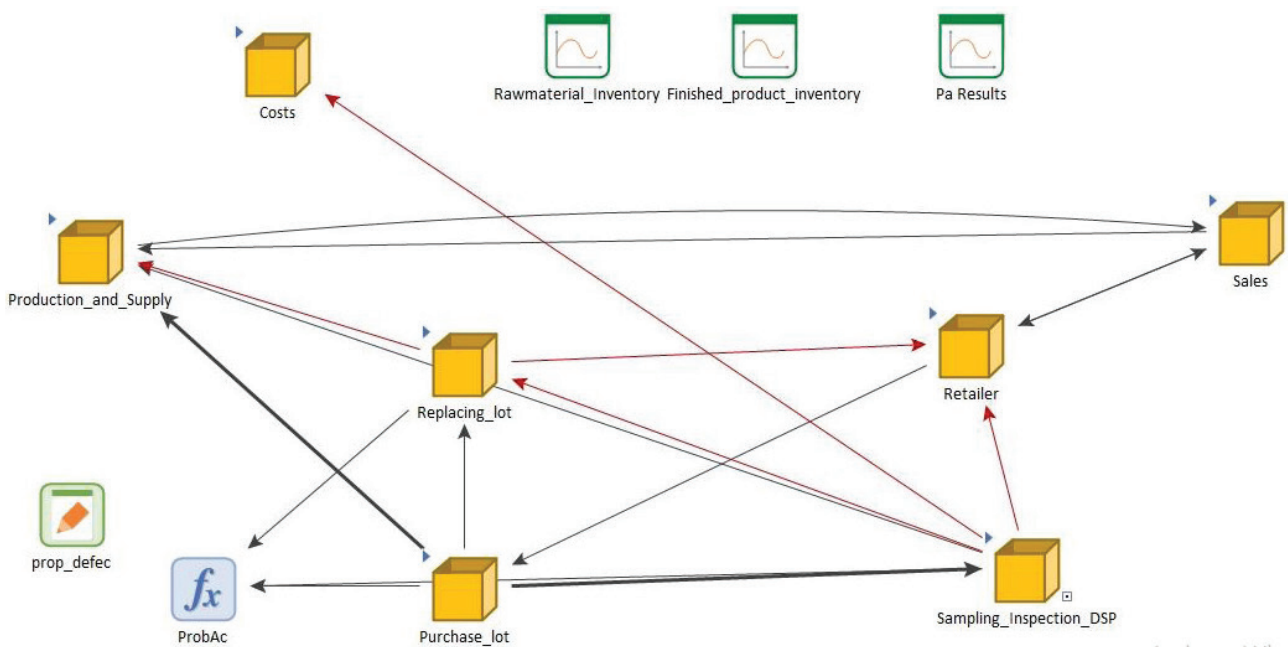
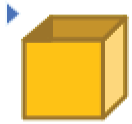
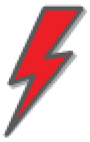
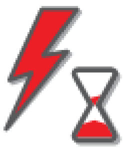


Figure 1. Simulation model for integrating DSP.

Table 1. The GoldSim elements used in simulation models

Elements	Description	Elements used in simulation models
	Simple (global) container	☐ Purchase lot ☐ Production and supply ☐ Sampling inspection for DSP ☐ Replacing lot ☐ Retailer ☐ Sales ☐ Cost
	Data source (input elements)	☐ Proportion defective ☐ Target quality ☐ Mean quality ☐ Inspection time ☐ Rectification time
	Expression element (Function element)	☐ Probability of acceptance
	Discrete change event	☐ Sampling inspection units ☐ Second sampling units ☐ Accepted lots ☐ Rejected lots ☐ Rectified items
	Random choice event	☐ First sample selection ☐ Second sample selection
	Discrete change delay	☐ Sampling delayed ☐ Screening

Simulating DSP(n, c_1, c_2), Optimum Lot Size and Total Cost Using Normal & Lognormal Distribution

In this section, the reward for the good items *(R_i)* and the penalty for the poor items *(P_i)* are fixed as Rs.0.5 and Rs.250 respectively. By fixing the demand values (D) as 500, 700 and 1000, for various *t(q)* and *m(q)*, the optimum *DSP(n, c_1, c_2)* plans along with the optimum lot sizes (N) and total costs (C) are simulated and listed in Table-2.

COMPARING DSP(n, c_1, c_2) BASED ON THE NORMAL AND THE LOGNORMAL DISTRIBUTIONS

The normal distribution led to a lower sample size than the lognormal distribution when other parameters are the same. The Figure 4, the Figure 5 and the Figure 6 demonstrate that the normal distribution produces double sampling plans integrated with SCC with smaller sample sizes than those associated with the lognormal distribution.

Example -1

Let us consider a scenario where a producer has established a contractual agreement with a consumer. The terms stipulate a reward of Rs. 0.5 per unit for achieving superior quality and a penalty of Rs. 250 per unit for any quality failures. The contract is designed to operate based on a target quality level, *t(q)* = 100, with a mean quality level of *m(q)* = 120 and a demand *(d)* of 500 units. Additionally, the product's lifetime is observed to follow a lognormal distribution. From Table 2, the optimal double sampling plan is

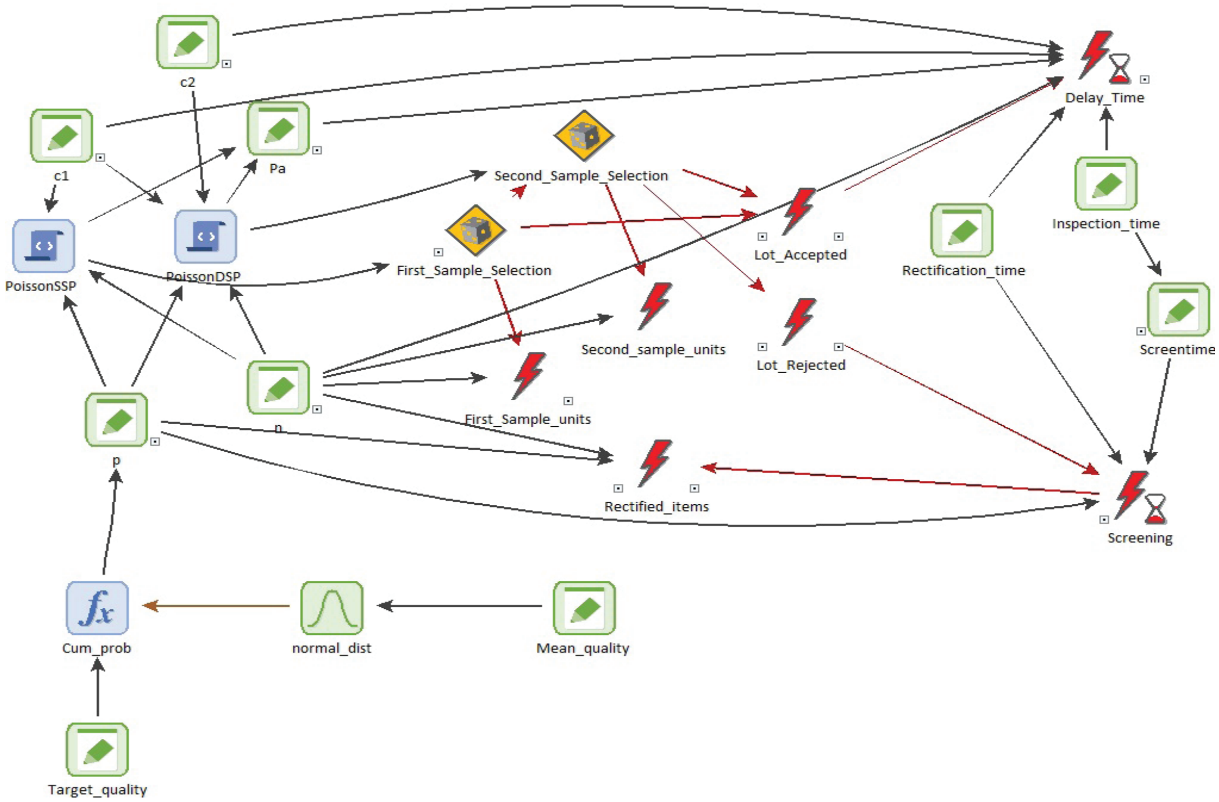


Figure 2. Normal distribution based simulation model for DSP with SCC.

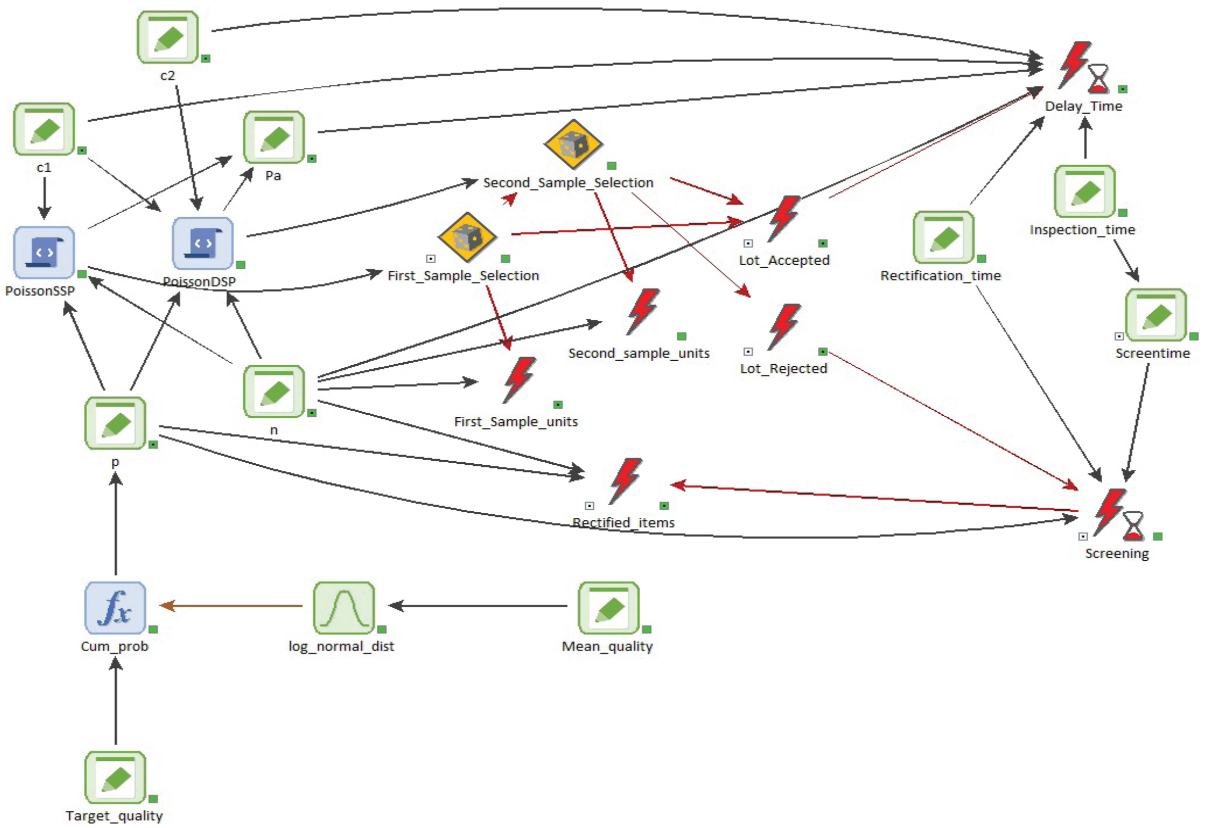


Figure 3. Lognormal distribution based simulation model for DSP with SCC.

Table 2. *DSP*(n, c_1, c_2) with (n, c) for various demand

t(q)	m(q)	D=500									D=700									D=1000								
		N	*DSP*(n, c_1, c_2) for lognormal				*DSP*(n, c_1, c_2) for normal				N	*DSP*(n, c_1, c_2) for lognormal				*DSP*(n, c_1, c_2) for normal				N	*DSP*(n, c_1, c_2) for lognormal				*DSP*(n, c_1, c_2) for normal			
			n	c_1	c_2	C	n	c_1	c_2	C		n	c_1	c_2	C	n	c_1	c_2	C		n	c_1	c_2	C	n	c_1	c_2	C
100	120	1999	182	5	7	1,96,32,100	161	4	9	1,96,31,800	2799	197	6	8	3,06,47,500	158	7	10	2,91,63,800	4193	157	3	5	4,56,40,500	157	7	12	4,34,50,500
120	125	1999	93	4	8	1,96,31,800	87	2	5	1,96,31,100	2799	189	3	7	2,91,63,600	89	3	9	2,90,57,000	4193	123	5	6	4,56,38,200	83	7	12	4,34,50,200
130	120	1999	94	3	6	1,96,31,500	56	5	10	1,96,31,000	2799	194	3	9	2,91,63,700	103	4	16	2,91,63,600	3999	97	8	10	4,34,51,800	90	6	14	4,34,50,000
140	125	1999	130	1	2	1,96,31,600	126	1	15	1,96,31,500	2799	150	6	8	2,91,63,500	93	7	17	2,91,63,500	3999	139	2	6	4,34,59,700	119	2	8	4,34,49,900
120	120	1999	127	1	4	1,96,31,900	116	3	15	1,96,31,900	2798	124	7	8	2,93,08,500	48	0	8	2,93,08,400	3999	135	1	7	4,34,50,900	117	2	20	4,34,50,200
130	130	1999	135	4	6	1,96,31,700	133	6	13	1,96,31,700	2798	158	1	7	2,93,08,500	106	2	19	2,93,08,400	4333	169	2	9	4,54,74,700	99	7	13	4,34,50,200
120	140	1999	103	1	6	1,96,32,000	96	2	15	1,96,31,200	2799	192	2	5	2,91,63,900	160	3	10	2,91,63,800	3999	143	4	9	4,34,50,500	108	8	11	4,34,50,400
130	140	1999	112	3	7	1,96,32,000	87	3	5	1,96,16,300	2799	148	2	10	3,05,54,300	133	3	12	2,91,63,700	3998	104	3	4	4,35,95,500	82	4	14	4,34,50,300
120	130	1999	157	1	8	1,96,31,700	106	6	8	1,96,31,100	2799	197	5	8	2,91,63,900	90	3	5	2,91,63,700	3999	117	5	8	4,34,50,500	109	1	12	4,34,50,30
125	135	1999	132	3	7	1,96,32,000	104	6	16	1,96,32,000	2799	95	3	7	2,91,63,900	91	6	16	2,91,63,700	3999	166	4	7	4,34,50,500	90	2	11	4,34,50,300
135	125	1999	111	5	6	2,06,27,200	98	3	11	1,96,31,900	2799	98	3	7	2,91,63,900	73	3	12	2,91,63,600	3999	166	5	8	4,34,50,800	100	6	10	4,34,50,000
125	130	1999	157	4	5	2,06,64,300	58	2	12	1,96,32,100	2799	143	1	10	2,91,63,900	112	5	14	2,91,63,700	3999	83	2	8	4,34,50,500	82	2	10	4,34,50,200
140	150	1999	161	9	10	1,96,31,700	147	2	15	1,96,31,000	2799	123	1	7	2,91,63,900	114	6	12	2,91,63,700	4333	110	4	6	4,54,80,400	81	4	14	4,34,50,300
130	135	1999	185	2	6	1,96,31,900	118	5	14	1,96,31,900	2799	79	2	6	2,91,63,900	66	5	14	2,91,63,700	3996	165	3	6	4,38,88,900	160	8	14	4,34,50,200
100	105	1999	161	1	3	1,96,31,700	84	5	16	1,96,31,100	2799	133	7	9	2,91,63,900	77	4	11	2,91,63,700	3999	135	4	9	4,34,51,100	121	5	12	4,34,50,300
100	110	1999	110	5	9	1,96,32,100	54	2	10	1,96,32,100	2799	112	3	7	2,91,63,900	60	5	10	2,91,63,900	3998	172	2	8	4,55,95,500	127	6	11	4,54,80,700
105	100	1999	171	4	5	1,96,31,800	80	5	13	1,96,31,000	3079	171	5	6	3,01,63,500	126	9	16	3,00,84,700	4193	184	4	8	4,56,40,200	115	7	13	4,34,50,100
110	100	1999	175	4	7	1,96,31,700	166	4	16	1,96,31,700	2799	195	4	6	3,05,54,100	100	8	13	2,91,63,600	3999	107	6	8	4,34,50,700	105	7	11	4,34,50,000

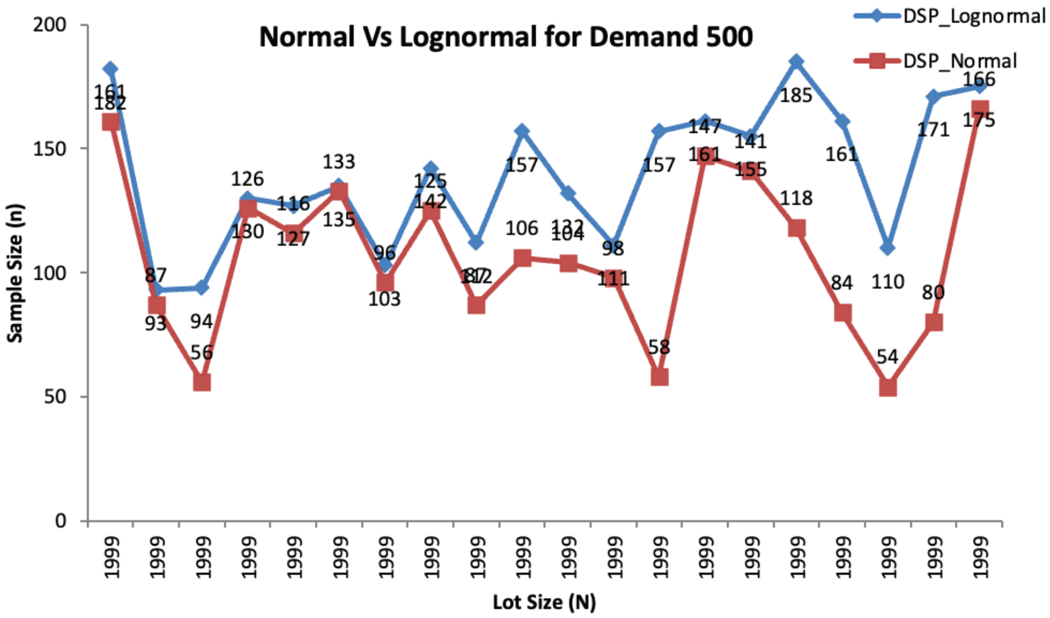


Figure 4. Sample sizes by normal and lognormal for demand = 500.

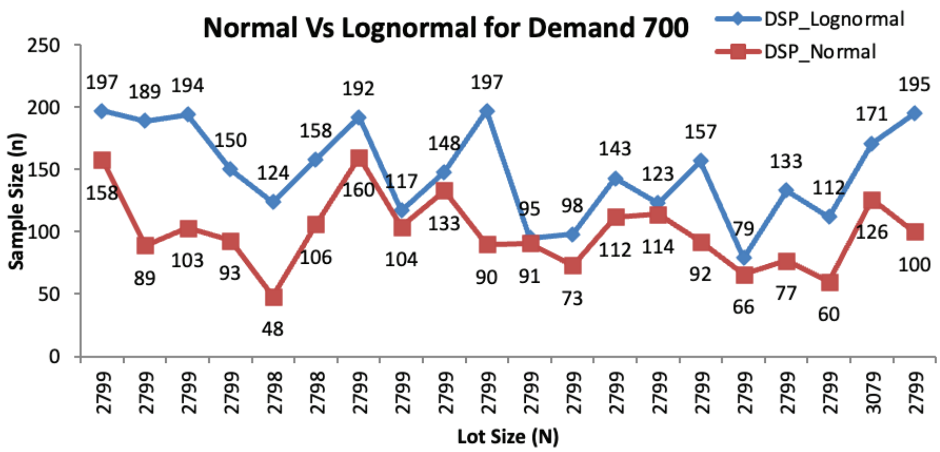


Figure 5. Sample sizes by normal and lognormal for demand = 700.

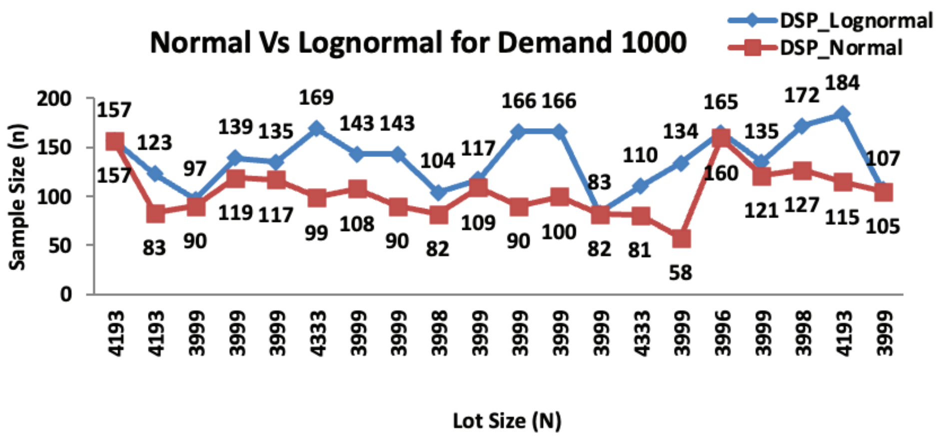


Figure 6. Sample sizes by normal and lognormal for demand = 1000.

identified as *DSP(182, 5, 7)*. The associated total cost (*C*) is determined as ₹1,96,32,100.

Example -2

Suppose a consumer purchasing electronic gadgets from a retailer. The retailer has entered into a contractual agreement with the manufacturer, which includes a reward of Rs. 0.5 per unit for delivering products of superior quality. However, the contract also imposes a penalty of Rs. 250 per unit for any instances of quality failures in the gadgets. The agreement is centered around achieving a target quality level, *t(q)* = 100, with a mean quality level of *m(q)* = 120. As a consumer, he anticipates a demand *(d)* for these gadgets to be 500 units. The manufacturer has determined the product's lifetime to follow a lognormal distribution. Through their commitment to quality, the manufacturer utilizes industry-standard tables, such as Table 2, to identify the optimal double sampling plan as *DSP(158, 7, 10*). The associated total cost *(C)* in this quality assurance plan is calculated to be ₹2,91,63,800, emphasizing the manufacturer's dedication to providing consumers with high-quality products and minimizing the risk of defects.

CONCLUSION

In this paper, Double Sampling Plans (DSPs) integrated with Supply Chain Contracts (SCC) is formulated, as detailed in the accompanying tables. These DSPs are applicable to products with lifetimes following either the lognormal or normal distribution. Through our comprehensive comparative analysis, it hasbeen determined that normal distribution results in more efficient DSPs integrated with SCC, characterized by a reduced sample size. Usingthe normal distribution for construction of DSP within SCC is identified as advantageous, leading to significant reductions in time, cost, and effort compared to the lognormal distribution. The detailed tables provided practical utility for industrial applications, and further research may explore the extension of this study to other sampling plans. More importantly, enterprises should attach great importance to the collective interests of the SCC, and provide coordination and convenience for other entities while focusing on their own development. This approach helps minimize the potential for risk interference in manufacturing industries.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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Annexure 1. Script used in GoldSim

```
Script:
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VALUE PROB = 0.0
VALUE pr1 = 1.0
FOR (j = c1+1; ~j <= c2; j = ~j + 1)
   VALUE fact = 1
   FOR (k = 1; ~k <= ~j; k = ~k + 1)
      fact = ~fact*~k
   END FOR // k
   pr1 = (n*p)^~j/~fact
   VALUE pr2 = 0
   FOR (i = 0; ~i <= c2-~j; i = ~i + 1)
      fact = 1
      FOR (k = 1; ~k <= ~i; k = ~k + 1)
         fact = ~fact*~k
      END FOR // k
      pr2 = (2*n*p)^~i/~fact+~pr2
   END FOR // i
   PROB = ~pr1*~pr2+~PROB
END FOR // j
Result = ~PROB*exp(-3*n*p)
```