A STUDY ON DESIGN OF CONTROL CHARTS USING TLBO

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Abstract - SPC is method of measuring and controlling quality by monitoring the manufacturing process. Quality data is collected in the form of product or process measurements or readings from various machines or instrumentation. The data is collected and used to evaluate, monitor and control a process. SPC is an effective method to drive continuous improvement. By monitoring and controlling a process, we can assure that it operates at its fullest potential. Among all the SPC tools, the control chart is most widely used in practice and control charts, $\bar{x}$ chart is the simplest to use for monitoring and controlling process in an industry. Process may go out of control due to shift in process mean and/or process variance. Hence to detect both type of shifts R chart is often used along with $\bar{x}$ chart.

***Key Words*:** SPC, quality, process, control charts

1. INTRODUCTION

1.1 Background

An organization must produce its output, whether product or service, with high quality at low cost to survive in the present days of competitive market. According to ISO the Quality Control is part of quality management focused on fulfilling requirements. Statistical Process Control (SPC) is a collection of problem solving tools useful in achieving process stability and improving capability through the reduction of variability using statistical methods. Among all SPC tools, the control chart is most widely used. It is a graphical tool used for checking whether the process is in control or out-of-control. $\bar{x}$ chart was first introduced by Shewhart(1931).

1.2 Control Chart

The control chart is a graph used to study how a process changes over time. Data are plotted in time order. A control chart always has a central line for the average, an upper line for the upper control limit, and a lower line for the lower control limit. These lines are determined from historical data.

1.3 $\bar{x}$ chart and R charts

In statistical quality control, the $\bar{x}$ and R chart is a type of control chart used to monitor variables data when samples are collected at regular intervals from a business or industrial process. The chart is advantageous in the following situations: The sample size is relatively small (say, $n \leq 10$—$\bar{x}$ and S charts are typically used for larger sample sizes) The sample size is constant. Humans must perform the calculations for the chart

The "chart" actually consists of a pair of charts: One to monitor the process standard deviation (as approximated by the sample moving range) and another to monitor the process mean, as is done with the $\bar{x}$ and s and individuals control charts. The $\bar{x}$ and R chart plots the mean value for the quality characteristic across all units in the sample. $R = x_{max} - x_{min}$.

1.4 Design of Control Chart

The ability of any control chart for detecting the changes in quality level obtained from a process depends on the effectiveness in design of control chart.

1.5 Research Gap

There are various types of control charts available for monitoring production processes and they are designed in different ways. These designs are optimized using different procedures.

In the first type of approach, the number of solution point is only one, whereas in the second type, it is more than one. One from these two different groups is selected for the present work i.e teaching-learning based optimization (TLBO). TLBO is population based technique it mimics the process of teaching a class of students. TLBO is one of the most recent and promising techniques. It is also observed TLBO has not been used for joint economic design of control charts. Further these optimization methods have never been used for economic statistical design of one control chart or joint economic statistical design of a group of charts. No comparison of results of economic design or economic statistical design obtained using TLBO technique between continuous and discontinuous processes has also been reported in literature.

1.6 Work Theme

On the basis of research gap as mentioned above, the main motivation for taking up this research work is to recommend a comprehensive package of designing control charts applicable to a variety of processes (i.e., continuous and discontinuous) subjected to all types of shifts (i.e., shift in process mean and/or process variance) based on economic as well as economic statistical performance. $\bar{x}$ chart has been selected as it is the most popularly used among all types of control charts for statistical process control in real practice due to its simplicity. Also many applications where this chart is used jointly with R chart.

2. Literature Review

2.1 Introduction

Industries are facing a considerable amount of challenges due to stiff competition. So market obviously requires quality of production in goods and services as well as for the growth of organization. So quality outputs are the main concern. Along with this a maximum profit margin w.r.t production cost is required at minimum possible level.

There are many quality management tools for controlling the quality of process output at minimum cost. Among them Shewhart Control Chart is widely used. It monitors the process quality by giving signal whenever the process shifts to out-of-control state. Its design involves the selection of three major variables, namely the sample size (n), the sampling interval (h) and the width of control limits (k). The number of variables may vary depending on the chart used. The effectiveness of designing a control chart depends on the technique used for optimizing the design to select the proper values of these design variables.

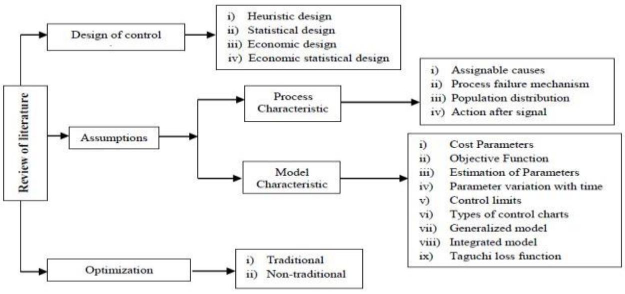

Fig 1:Categorization of review articles

2.2 Quality

Quality is undoubtedly one of the most important decision factors for a customer while purchasing a product or service. He prefers to buy a quality product but it should be available at an affordable price. The term quality has been defined in many ways.

2.3 Dimensions of Quality

A product quality can be described in many ways such as performance, reliability, durability, serviceability, aesthetics, features, perceived quality, and conformance to standards.

2.4 Quality Engineering

A group of engineering, operational and managerial activities that a firm uses to ensure that the quality characteristics of a product are at the nominal or required levels and that the variability around these desired level is minimum is known as quality engineering.

2.5 Quality Management

The achievement of desired quality requires the dedication and cooperation of all members of the organization, whereas the responsibility for quality management belongs to top administration. Quality management comprises of strategic planning, resources allocation, and other systematic activities for quality, such as quality planning, operation, and evaluation.

2.6 Quality Assurance

It is the manufacturer's responsibility who has to study the requirements of the customers in details, interpret their ideas and make every effort to produce the product that suits the requirements of customers satisfactorily.

2.7 Quality Control

It is a process by which entities review the quality of all factors involved in production.

2.8 Statistical Process Control

Statistical process control (SPC) is a method of quality control which employs statistical methods to monitor and control a process. This helps to ensure that the process operates efficiently, producing more specification-conforming products with less waste (rework or scrap). It consists of the following seven problem solving tools:

Histogram

Check sheet

Cause and effect diagram

Pareto chart

Defect concentration diagram

Scatter diagram

Control chart

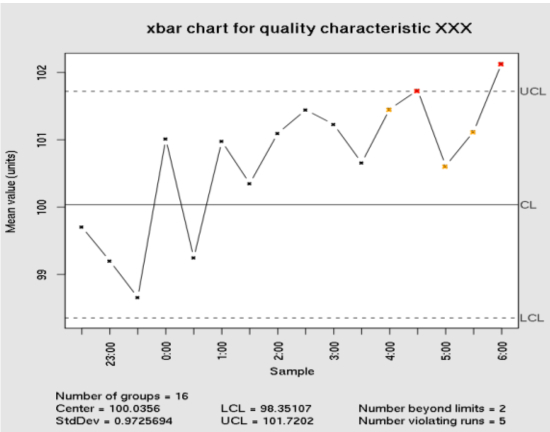

Fig 2: Xbar chart for quality characteristic

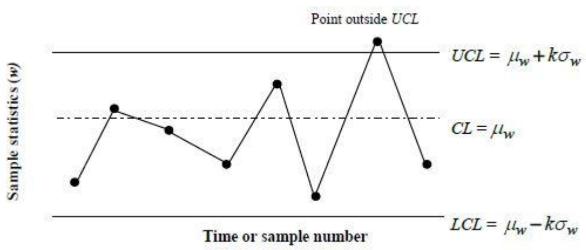

Fig 3:A Shewhart Control Chart

Center line at CL; Upper control limit at UCL; Lower control limit at LCL, where k = width of control limits expressed in standard deviation unit.

2.9 Design of Control Chart

Heuristic design,

Statistical design,

Economic design and

Economic statistical design.

In the next four sections these design methods are explained in details

2.10 Heuristic Design

Shewhart control chart are most often designed heuristically in practice because it is easy to understand and implement with little operative training. The below table different guidelines suggested by various researchers for selection of design variables in case of $\bar{x}$ chart.

Authors	Design variables
Burr (1953)	n = 4 or 5, h =? and k = 3
Feigenbaum (1961)	n = 5, h = 1 and k = 3
Juran et al. (1974)	n = 4, h =? and k = 3
Ishikawa (1976)	n = 5, h = 8 and k = 3

Table 1: Guidelines for heuristic design of $\bar{x}$ chart

2.11 Statistical Design

A type of experimental design that allows for the statistical analysis and control of external variables. Examples of statistical design are: randomized blocks, Latin square, and factorial design.

Authors	*Control Charts*
Woodall (1985)	X and CUSUM
Keats et al. (1995)	X
Wu et al. (2002)	X and S jointly
De-Magalhaes (2006)	X and R jointly
Chen (2007)	Variable parameter T^2 chart

Table 2: Summary of literature on statistical design

2.12 Economic Design

Economic Design refers to sustainability from a more resilient and participatory future. Participants will learn about existing systems and tools that are useful, and will explore what it might take to re-design those that have proven dysfunctional.

Authors	*Major Contribution*
Girshick and Rubin (1952)	Introduced the first cost based models in control chart design
Weiler (1952)	Semi-economic design
Duncan (1956)	First proposed an economic model for design of X chart
Savage (1962)	Generalized semi-economic design
Barish and Hauser (1963)	Semi-economic design of Girshick and Rubin (1952) model
Ross (1971)	Suggested renewal reward process
Krishnamoorthi (1985)	Comparison between economic and heuristic designs of X chart
Lorenzen and Vance (1986)	Unified approach in economic design model
Svoboda (1991)	Review of literature from 1979-1989

Table 3: Summary of literature on economic design

2.13 Joint Economic Design

Most of the researchers considered only one control chart at a time for its economic design. But, $\bar{x}$ chart is often used along with R chart in practice for simultaneous monitoring of process mean and process variance. Therefore, some researchers have developed economic models for simultaneous design of both these charts. This type of design is known as joint economic design.

Authors	*Major Contributions*
Saniga (1977)	First to introduce a joint economic design model
Saniga (1979)	Single assignable cause using geometric, Poisson and logarithmic series distributions
Saniga and Montgomery (1981)	Single assignable cause using normal distribution
Jones and Case (1981)	Both single and multiple assignable cause
Chung and Chen (1993)	Developed optimization algorithm
Costa (1993)	Two independent assignable causes

Table 4: Summary of literature on joint economic design

3. Economic Design of $\bar{x}$ Chart

3.1 Introduction

$\bar{x}$ is chart is most commonly used for statistical process control in industries. Hence, its design from economic point of view has gained considerable importance. This type of design minimizes the cost of process control and thereby helps in improving profit margin of the industry in competitive market.

In this chapter, new methodologies for economic design of $\bar{x}$ chart based on metaheuristic approaches such as teaching-learning based optimization (TLBO) have been developed for both continuous and discontinuous types of processes.

3.2 Numerical Illustration: Continuous Process

In order to illustrate the working of optimization methodology, a numerical problem dealing with continuous process has been taken from Panagos et al., (1985) where the cost and process data are as listed in Table 5 and has been solved using TLBO.

S. No.	*Cost and process parameter*	*Notation*	*Unit*	*Value*
1	Loss of income when process is out-of-control	M	$	100
2	Shift in process mean	δ	-	1
3	Rate of occurrence of assignable cause	λ	per hour	0.05
4	Time to sample and chart one item	g	hour	0.05
5	Time to find and repair an assignable cause	T_1+T_2	hour	3
6	Fixed cost per sample	a	$	0.5
7	Variable cost per sample	b	$	1.0
8	Cost to locate and repair the assignable cause	W	$	250
9	Cost per false alarm	Y	$	50

Table 5: Cost and process data: Continuous process

3.3 Results and Discussion: TLBO

The values of relevant data of this problem are already listed in above tables. The results of economic design of $\bar{x}$ chart for a continuous process using TLBO are shown in Table 6 for each integer value of sample size n in the range 2 to 33.

n	*h*	*k*	α	β	*P*	ARL_0	ARL_1	$E(L)_1$
2	1.05	1.71	0.0873	0.615	0.385	11.459	2.600	36.521
3	1.32	1.72	0.0854	0.495	0.505	11.705	1.980	35.538
4	1.57	1.74	0.0819	0.397	0.603	12.215	1.659	35.034
5	1.79	1.76	0.0784	0.317	0.683	12.753	1.464	34.795
6	**1.99**	**1.80**	**0.0719**	**0.258**	**0.742**	**13.914**	**1.348**	**34.720**
7	2.18	1.83	0.0673	0.207	0.793	14.868	1.262	34.757
8	2.35	1.87	0.0615	0.169	0.831	16.261	1.203	34.872
9	2.51	1.91	0.0561	0.138	0.862	17.810	1.160	35.044
10	2.66	1.95	0.0512	0.113	0.887	19.534	1.127	35.259
11	2.80	2.00	0.0455	0.094	0.906	21.970	1.104	35.507
12	2.93	2.04	0.0414	0.077	0.923	24.173	1.084	35.779
13	3.06	2.08	0.0375	0.064	0.936	26.635	1.068	36.069
14	3.19	2.13	0.0332	0.054	0.946	30.128	1.057	36.374
15	3.31	2.17	0.0300	0.044	0.956	33.302	1.046	36.688
16	3.43	2.21	0.0271	0.037	0.963	36.864	1.038	37.011
17	3.54	2.25	0.0245	0.031	0.969	40.865	1.032	37.339
18	3.65	2.3	0.0215	0.026	0.974	46.576	1.027	37.671
19	3.76	2.34	0.0193	0.022	0.978	51.799	1.022	38.005
20	3.87	2.38	0.0173	0.018	0.982	57.689	1.019	38.340
21	3.97	2.42	0.0155	0.015	0.985	64.343	1.016	38.675
22	4.08	2.47	0.0135	0.013	0.987	73.900	1.013	39.010
23	4.18	2.51	0.0121	0.011	0.989	82.692	1.011	39.343
24	4.28	2.55	0.0108	0.009	0.991	92.665	1.010	39.675
25	4.38	2.59	0.0096	0.008	0.992	103.990	1.008	40.004
26	4.48	2.63	0.0086	0.007	0.993	116.870	1.007	40.331
27	4.57	2.67	0.0076	0.006	0.994	131.540	1.006	40.656
28	4.67	2.71	0.0067	0.005	0.995	148.270	1.005	40.977
29	4.76	2.75	0.0060	0.004	0.996	167.370	1.004	41.296
30	4.86	2.79	0.0053	0.004	0.996	189.210	1.004	41.611
31	4.95	2.83	0.0047	0.003	0.997	214.210	1.003	41.924
32	5.04	2.86	0.0042	0.003	0.997	235.330	1.003	42.233
33	5.14	2.9	0.0037	0.002	0.998	267.120	1.002	42.539

Table 6: Optimal economic designs of $\bar{x}$ chart using TLBO: continuous process

On comparing all 32 economic designs, one each for integer value of sample size n varying from 2 to 33, the optimal expected loss cost per unit time is observed to be $E(L)_1$=34.720 and this occurs at n=6 as shown in table above. Here the values of expected loss cost per unit time $E(L)_1$ decreases with increase of n value from 2 to 6 and after that it increases at higher values of n. The corresponding values of h and k at minimum loss cost are 1.99 and 1.80 respectively.

Techniques	*n*	*h*	*k*	α	β	*P*	ARL_0	ARL_1	$E(L)_1$
TLBO	6	1.99	1.80	0.0719	0.258	0.742	13.914	1.348	34.720

Table 7: Results obtained from TLBO in continuous process

3.4 Numerical Illustration: Discontinuous Process

A numerical problem related to economic design of $\bar{x}$ chart for discontinuous process already solved by Panagos et al. (1985) has been considered here to investigate the effectiveness of simulated annealing optimization technique. In addition to the nine cost and process parameters corresponding to the continuous process, this process deals with four additional parameters i.e., V_0, S, S_1 and T_0. The values of all the thirteen cost and process parameters associated with a discontinuous process in this numerical problem along with their notations are listed in Table 8.

S. No.	*Cost and process parameters*	*Notation*	*Unit*	*Value*
1	Loss of income when process is out-of-control	M	$	100
2	Shift in process mean	δ	-	1
3	Rate of occurrences of assignable causes	λ	per hour	0.05
4	Time to sample and chart one item	g	hour	0.05
5	Time to find and repair an assignable cause	T_1+T_2	hour	3
6	Fixed cost per sample	a	$	0.5
7	Variable cost per sample	b	$	1.0
8	Cost to locate and repair the assignable cause	W	$	250
9	Cost per false alarm	Y	$	50
10	Net income per hour while process is in-control	V_0	$	50
11	Expected cost of restart or setup cost	S	$	100
12	Time to restart the process	S_1	hour	1
13	Expected search time for a false alarm	T_0	hour	40

Table 8: Cost and process data: discontinuous process

3.5 Results and Discussion: TLBO

The numerical problem solved using has been considered to illustrate the design methodology based on TLBO for a discontinuous process. The values of relevant data of this problem are already listed in Table. Similarly to Table, the results of economic design of $\bar{x}$ chart for a discontinuous process using TLBO are shown in Table 9 for each integer value of sample size n in the range 2 to 33.

n	*h*	*k*	α	β	*P*	ARL_0	ARL_1	$E(L)_2$
2	0.63	2.47	0.0135	0.854	0.146	73.900	6.869	42.846
3	0.81	2.53	0.0114	0.788	0.212	87.521	4.707	40.899
4	1.01	2.57	0.0102	0.716	0.284	98.147	3.517	39.478
5	1.21	2.60	0.0093	0.642	0.358	107.060	2.794	38.429
6	1.41	2.62	0.0088	0.568	0.432	113.500	2.313	37.649
7	1.61	2.65	0.0081	0.502	0.498	123.970	2.007	37.069
8	1.81	2.67	0.0076	0.437	0.563	131.540	1.776	36.645
9	1.99	2.69	0.0072	0.378	0.622	139.630	1.608	36.344
10	2.17	2.71	0.0067	0.326	0.674	148.270	1.483	36.141
11	2.34	2.73	0.0063	0.279	0.721	157.500	1.387	36.020
12	**2.50**	**2.75**	**0.0060**	**0.238**	**0.762**	**167.370**	**1.312**	**35.966**
13	2.65	2.77	0.0056	0.202	0.798	177.920	1.253	35.968
14	2.79	2.79	0.0053	0.171	0.829	189.210	1.206	36.018
15	2.93	2.82	0.0048	0.146	0.854	207.640	1.171	36.108
16	3.06	2.84	0.0045	0.123	0.877	221.010	1.140	36.231
17	3.18	2.87	0.0041	0.105	0.895	242.870	1.117	36.383
18	3.30	2.89	0.0039	0.088	0.912	258.760	1.097	36.559
19	3.41	2.92	0.0035	0.075	0.925	284.740	1.081	36.755
20	3.52	2.95	0.0032	0.064	0.936	313.600	1.068	36.968
21	3.63	2.97	0.0030	0.053	0.947	334.610	1.056	37.195
22	3.73	3.00	0.0027	0.045	0.955	369.030	1.048	37.434
23	3.83	3.03	0.0025	0.039	0.961	407.340	1.040	37.683
24	3.93	3.05	0.0023	0.032	0.968	435.260	1.033	37.939
25	4.02	3.08	0.0021	0.027	0.973	481.110	1.028	38.202
26	4.12	3.11	0.0019	0.023	0.977	532.230	1.024	38.469
27	4.21	3.14	0.0017	0.020	0.980	589.280	1.020	38.741
28	4.30	3.16	0.0016	0.017	0.983	630.970	1.017	39.015
29	4.39	3.19	0.0014	0.014	0.986	699.570	1.014	39.292
30	4.48	3.22	0.0013	0.012	0.988	776.290	1.012	39.569
31	4.56	3.25	0.0012	0.010	0.990	862.150	1.010	39.848
32	4.65	3.27	0.0011	0.009	0.991	925.030	1.009	40.126
33	4.74	3.30	0.0010	0.007	0.993	1028.800	1.007	40.404

Table 9: Optimal economic designs of $\bar{x}$ chart using TLBO: discontinuous process

On comparing the results of all 32 economic designs, one each for integer value of sample size n varying from 2 to 33, the most minimum expected loss cost per unit time is found to be $E(L)_2$ = 35.966 and this occurs at n = 12 as shown in Table. The corresponding values of h and k at minimum loss cost are 2.50 hour and 2.75 respectively.

Techniques	*n*	*h*	*k*	α	β	*P*	ARL_0	ARL_1	$E(L)_2$
TLBO	12	2.50	2.75	0.0060	0.238	0.762	167.370	1.312	35.966

Table 10: Results obtained from TLBO: Discontinuous process

3.6 Summary of Results

Similar to Table, all the significant factors in case of economic design for discontinuous process corresponding to each of the four responses are summarized in Table. This table is expected to be helpful for the control chart designers in case of discontinuous process. This table also compares the results of present work for a discontinuous process with that reported earlier by Panagos et al. (1985).

Output responses	*Methodology*	*Cost and process parameters*												
		M	δ	λ	*g*	(T_1+T_2)	*a*	*b*	*W*	*Y*	V_0	*S*	S_1	T_0
n	Panagos et al. (1985)		–		–									
	Present work		–		–									
h	Panagos et al. (1985)	–	–	–			+	+						
	Present work	–	–	–		+	+	+			+			
k	Panagos et al. (1985)		–	–	–		–	–		+	+			+
	Present work		+	–	–		–	–		+	+			+
$E(L)_2$	Panagos et al. (1985)	+		+		+					+			
	Present work	+		+		+					+			

Table 11: Summary of significant effects in economic design: discontinuous process

Note:

Blank space: Insignificant factor

\+ : Factor with positive effect

– : Factor with negative effect

+/– in bold: Most significant factor

Table above shows that only in case of sampling interval h, the most significant factors are different in both sets of results. Panagos et al. (1985) reported that the rate of occurrences of assignable cause is the most significant factor for sampling interval h, whereas the results obtained in the present work show that the variable cost per sample b is the most significant factor for h. Further, all other significant factors are observed to be completely same in both sets of results for all the responses except one i.e., sampling interval h. Two factors i.e., the time to find and repair an assignable cause (T_1+T_2) and net income per hour while process is in-control V0 are found in the present work to have significant effect on the sampling interval *h*, whereas they are reported to be insignificant by Panagos et al. (1985) for *h*. Total Cost Model: Numerical Illustration

In order to investigate the effectiveness of design methodologies based on metaheuristics (i.e., TLBO) another numerical problem that was earlier solved by van Deventer and Manna (2009) has been considered. This is related to economic design of $\bar{X}$ chart for a continuous process. In this problem, the economic model is slightly different.

3.7 Cost and Process Parameters

The numerical data dealing with a continuous process has been taken from van Deventer and Manna (2009) where the values of cost and process parameters are as listed in Table below.

S. No.	Cost and process parameters	Notation	Unit	Value
1	Quality cost per hour while producing in-control	C_0	ZAR	10
2	Quality cost per hour while producing out-of-control	C_1	ZAR	100
3	Shift size from the mean	δ	-	1
4	Rate of occurrences of assignable causes	λ	per hour	0.01
5	Time to sample and chart one item	g	hour	0.05
6	Time to find the assignable cause	T_1	hour	2
7	Time to repair the assignable cause	T_2	hour	0
8	Fixed cost per sample	a	ZAR	0.5
9	Variable cost per sample	b	ZAR	0.1
10	Cost to locate and repair the assignable cause	W	ZAR	25
11	Cost per false alarm	Y	ZAR	50

Table 12: Cost and process parameters (van Deventer and Manna, 2009)

3.8 Results and Discussion: TLBO

The same numerical problem related to economic design of a continuous process mentioned has been again solved using TLBO for cross checking the accuracy of results. Similarly, the results of economic design obtained using TLBO are shown for each integer value of sample size n in the range 1 to 20.

n	h	k	α	β	P	ARL_0	ARL_1	E(Q)
1	0.60	2.16	0.0308	0.876	0.124	32.474	8.077	19.204
2	0.69	2.29	0.0220	0.809	0.191	45.365	5.244	17.352
3	0.81	2.35	0.0188	0.732	0.268	53.205	3.727	16.422
4	0.94	2.39	0.0169	0.652	0.348	59.277	2.871	15.870
5	1.07	2.42	0.0155	0.573	0.427	64.343	2.342	15.513
6	1.20	2.45	0.0143	0.500	0.500	69.899	2.001	15.273
7	1.33	2.48	0.0132	0.434	0.566	75.996	1.767	15.107
8	1.45	2.50	0.0124	0.371	0.629	80.390	1.591	14.994
9	1.56	2.53	0.0114	0.319	0.681	87.521	1.469	14.919
10	1.66	2.56	0.0105	0.274	0.727	95.362	1.377	14.871
11	1.76	2.59	0.0096	0.234	0.766	103.992	1.305	14.846
12	**1.85**	**2.62**	**0.0088**	**0.199**	**0.801**	**113.495**	**1.249**	**14.838**
13	1.93	2.65	0.0081	0.170	0.830	123.969	1.204	14.844
14	2.01	2.68	0.0074	0.144	0.856	135.521	1.169	14.861
15	2.09	2.71	0.0067	0.122	0.878	148.271	1.140	14.887
16	2.16	2.75	0.0060	0.106	0.894	167.370	1.118	14.921
17	2.23	2.78	0.0055	0.090	0.910	183.470	1.098	14.961
18	2.29	2.81	0.0050	0.076	0.924	201.284	1.082	15.006
19	2.35	2.85	0.0044	0.066	0.934	228.050	1.070	15.056
20	2.41	2.88	0.0040	0.056	0.944	250.677	1.059	15.109

Table 13: Optimal economic designs: TLBO

On comparing all 20 economic designs, the minimum value of E(*Q*) is found to be 14.838 and this occurs at sample size *n* = 12. The values of expected total cost per hour E(*Q*) decreases with the increase of *n* value from 1 to 12 and after that it increases at higher values of *n*. The corresponding values of *h* and *k* at minimum loss cost are 1.85 hour and 2.62 respectively. This trend is also graphically illustrated.

Techniques	n	h	k	α	β	P	ARL_0	ARL_1	E(Q)
TLBO	12	1.85	2.62	0.0088	0.199	0.801	113.495	1.249	14.838

Table 14: The above table shows results obtained from TLBO

3.9 Conclusions

The major contribution of this chapter is development of design methodologies based on metaheuristics, TLBO for economic design of $\bar{x}$ chart for both continuous and discontinuous processes. This methodology have been illustrated through numerical examples taken from literature. It is observed that both are providing nearly the same results and hence any of them can be recommended for use. Moreover, they are providing better results than that reported earlier in the literature. From the results of sensitivity analysis it can be concluded that the shift in process mean is the most significant factor affecting the selection of sample size n in both continuous and discontinuous processes and its effect is in negative direction. Similarly, the rate of occurrences of assignable cause is the most significant factor affecting the expected loss cost per unit time E(L) its effect is of positive type. For the width of control limits k, the cost per false alarm Y is observed to have the maximum effect in a continuous process, whereas the variable cost of sampling b is the most significant factor in a discontinuous process. For the sampling interval h, the fixed cost per sample a is the most significant factor in a continuous process, whereas the variable cost per sample b is the most significant factor in a discontinuous process.

4. Future Scope

4.1 Future Scope of Research and Conclusions

A process may shift to out-of-control state due to shift in process mean or process variance or both. The objective of the thesis is to design control charts for detecting the process shift as quickly as possible and at the same time with minimum possible cost. In the present work the key contribution is the development of design methodologies based on meatheuristics, teaching-learning based optimization (TLBO) for the following two design problems: Economic design of $\bar{x}$ chart for continuous process. Economic design of $\bar{x}$ chart for discontinuous process.

4.2 Conclusions

On the basis of the results obtained out of the present work, the following conclusions is drawn. TLBO is providing superior results than that of the corresponding results reported earlier in the literature.

References

1. Aghabeig, D. and Moghadam, M.B. (2013) "Economic design of $\bar{x}$ control charts under generalized exponential shock models with uniform sampling intervals", European Online Journal of Natural and Social Sciences, Vol.2, No. 3, pp. 1540-1545.

2. Ahmed, I., Sultana, I., Paul, S.K. and Azeem, A. (2014) "Performance evaluation of control chart for multiple assignable causes using genetic algorithm", The International Journal of Advanced Manufacturing Technology, Vol. 70, No. 9, pp. 1889-1902.

3. ANSI/ASQC A1. (1978) "Definitions, symbols, formulas and tables for control charts", American Society for Quality Control, Milwaukee, USA.

4. Arnold, B.F. (1989) "Optimal control charts and discrimination between acceptable and unacceptable states", Sankhya: The Indian Journal of Statistics, Series B, Vol. 51, No. 3, pp. 375-389.

5. Arnold, B.F. and Collani, E.V. (1989) "On the robustness of $\bar{x}$ charts", Statistics, Vol. 20, No.1, pp. 149-159.

6. Burr, I.W. (1953) "Engineering statistics and quality control", McGraw-Hill Book Company, New York, NY.

7. Ganguly,A ECONOMIC DESIGN OF CONTROL CHARTS USING METAHEURISTIC APPROACHES.

8. Ganguly, A. and Patel S.K. (2012) "Economic design of $\bar{x}$ control chart using simulated annealing", Procedia Engineering, Vol. 38, pp. 1037-1043.