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INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR
Department of Industrial and Systems Engineering
Mid Autumn Semester Examination, 2018
Third Year B.Tech.(H)/Dual Degree in IM, QE and QM

Subject Number: IM31005 **Subject Name:** Quality Design and Control
Full Marks: 60 **Time:** 2 Hours
Date, Time, and Venue of Examination: 25.09.2018, 14.00-16.00, S301/NC343/NC344/NC131/NC333/NC334
Number of Students Appearing in the Examination: 75

Instructions : 1. **Attempt all questions.**
2. Maximum marks are shown against each question.
3. Answers should be short and to the point.
4. Statistical and other tables as required are attached with the question paper.

Q.1 (a) State any three reasons of adopting Taguchi's Quality Engineering concept for products and processes. Formulate the problem of product robustness, in functional form only, assuming relevant variables, parameters, and constraints. **(1.5 + 3)**

(b) How would you construct an OC curve for a control chart? How can its discriminatory power be improved? What is the main limitation of an ARL curve? **(2 + 1 + 1)**

(c) A manager is contemplating using Rules 1 and 4 for determining out-of-control conditions. Suppose that the manager constructs 3σ limits.

(i) What is the overall Type-I error probability assuming independence of the rules? **(4)**

(ii) On average, how many samples will be analyzed before detecting a change in the process mean? Assume that the process mean is now at 110 mm (having moved from 105 mm) and that the process standard deviation is 6 mm. Samples of size 4 are selected from the process. **(2.5)**

Q.2 (a) Cite three examples for each of internal and external failure costs in a typical discrete-part manufacturing system. How would you measure and evaluate them? Establish their relationship with 'prevention' and 'appraisal' costs. **(1.5 x 2 + 1 x 2 + 3)**

(b) Show, by means of graphical representation only, the transition among Quality, Cost, and Profit. **(3)**

(c) Explain, in brief (with two sentences only for each), the concept of 'Design for Manufacturing' and 'Design for Supply Chain' in the context of TQM.

(2 + 2)

PTO

Q.3 (a) The following fraction nonconforming control chart with $n = 100$ is used to control a process:
LCL = 0.0050, Center line = 0.0400, UCL = 0.0750.
(i) Use Poisson approximation to binomial to find the probability of a Type-I error. (2)
(ii) Use Poisson approximation to binomial to find the probability of a Type-II error, if the true process fraction nonconforming is 0.0600. (2)
(iii) Draw the OC curve for this control chart. (3)
(iv) Find the ARL when the process fraction nonconforming is 0.0600. (1)

(b) The manufacturer wishes to set up a control chart at the final inspection station for a gas water heater. Defects in workmanship and visual quality features are checked in this inspection. For the past 22 working days, 176 water heaters were inspected and a total of 924 nonconformities reported.

(i) What type of control chart would you recommend here and how would you use it? (1)
(ii) Using two water heaters as the inspection unit, calculate the centre line and control limits that are consistent with the past 22 days of inspection data. (2)

(c) How do you use modified and acceptance control charts? Under what process conditions are they used? (3 + 1)

Q.4 (a) Control charts for $\bar{X}$and R are maintained for an important quality characteristic. The sample size is 7. After35 samples, we have found that

$$\sum_{i=1}^{35} \bar{X}_i = 7805 \text{ and } \sum_{i=1}^{35} R_i = 1200$$

(i) Set up $\bar{X}$and R charts using these data. (2)
(ii) Assuming that both charts exhibit control, estimate the process mean and standard deviation. (1)
(iii) If the quality characteristic is normally distributed and if the specifications are 220 ± 35, can the process meet the specifications? Estimate the fraction nonconforming. (2)
(iv) Assuming the variance to remain constant, state where the process mean should be located to minimize the fraction nonconforming. What would be the value of the fraction nonconforming under these conditions? (1 + 1)

(b) In 1879, A. A. Michelson measured the velocity of light in air using a modification of a method proposed by the French physicist Foucauld. Twenty of these measurements are given in the Table (the value reported is in kilometers per second and has 299,000 subtracted from it). Use these data to set up an individual and a moving range control chart. Do the measurements exhibit statistical control? Revise the control limits if necessary. **(2 + 2 + 2)**

Measurement	Velocity	Measurement	Velocity
1	850	11	850
2	1000	12	810
3	740	13	950
4	980	14	1000
5	900	15	980
6	930	16	1000
7	1070	17	980
8	650	18	960
9	930	19	880
10	760	20	960

(c) Why do you use a Box plot and a three-dimensional Scatter plot? **(1 + 1)**

TABLE A.1 Cumulative Normal Distribution

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
−3.40	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
−3.30	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
−3.20	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
−3.10	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
−3.00	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
−2.90	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
−2.80	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
−2.70	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
−2.60	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
−2.50	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
−2.40	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
−2.30	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
−2.20	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
−2.10	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
−2.00	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
−1.90	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
−1.80	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
−1.70	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
−1.60	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
−1.50	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
−1.40	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
−1.30	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
−1.20	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
−1.10	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
−1.00	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
−.90	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
−.80	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
−.70	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
−.60	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
−.50	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
−.40	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
−.30	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
−.20	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
−.10	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
−.00	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

TABLE A.1 Cumulative Normal Distribution *continued*

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.00	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.10	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.20	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6046	.6103	.6141
.30	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.40	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.50	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.60	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.70	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.80	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.90	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.00	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.10	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.20	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.30	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.40	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.50	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	9429	.9441
1.60	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.70	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.80	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.90	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.00	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.10	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.20	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.30	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.40	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.50	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.60	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.70	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.80	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.90	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.00	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.10	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.20	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.30	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997

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TABLE A.2 Cumulative Poisson Distribution

λ = *Mean*

X	.01	.05	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	.990	.951	.905	.819	.741	.670	.607	.549	.497	.449	.407
1	1.000	.999	.995	.982	.963	.938	.910	.878	.844	.809	.772
2		1.000	1.000	.999	.996	.992	.986	.977	.966	.953	.937
3				1.000	1.000	.999	.998	.997	.994	.991	.987
4						1.000	1.000	1.000	.999	.999	.998
5									1.000	1.000	1.000

X	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0	.368	.333	.301	.273	.247	.223	.202	.183	.165	.150	.135
1	.736	.699	.663	.627	.592	.558	.525	.493	.463	.434	.406
2	.920	.900	.879	.857	.833	.809	.783	.757	.731	.704	.677
3	.981	.974	.966	.957	.946	.934	.921	.907	.891	.875	.857
4	.996	.995	.992	.989	.986	.981	.976	.970	.964	.956	.947
5	.999	.999	.998	.998	.997	.996	.994	.992	.990	.987	.983
6	1.000	1.000	1.000	1.000	.999	.999	.999	.998	.997	.997	.995
7					1.000	1.000	1.000	1.000	.999	.999	.999
8									1.000	1.000	1.000

X	2.2	2.4	2.6	2.8	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0	.111	.091	.074	.061	.050	.030	.018	.011	.007	.004	.002
1	.355	.308	.267	.231	.199	.136	.092	.061	.040	.027	.017
2	.623	.570	.518	.469	.423	.321	.238	.174	.125	.088	.062
3	.819	.779	.736	.692	.647	.537	.433	.342	.265	.202	.151
4	.928	.904	.877	.848	.815	.725	.629	.532	.440	.358	.285
5	.975	.964	.951	.935	.916	.858	.785	.703	.616	.529	.446
6	.993	.988	.983	.976	.966	.935	.889	.831	.762	.686	.606
7	.998	.997	.995	.992	.988	.973	.949	.913	.867	.809	.744
8	1.000	.999	.999	.998	.996	.990	.979	.960	.932	.894	.847
9		1.000	1.000	.999	.999	.997	.992	.983	.968	.946	.916
10				1.000	1.000	.999	.997	.993	.986	.975	.957
11						1.000	999	.998	.995	.989	.980
12							1.000	.999	.998	.996	.991
13								1.000	.999	.998	.996
14									1.000	.999	.999
15										1.000	.999
16											1.000

TABLE A.2 Cumulative Poisson Distribution *continued*

	λ = Mean										
X	6.5	7.0	7.5	8.0	9.0	10.0	12.0	14.0	16.0	18.0	20.0
0	.002	.001	.001								
1	.011	.007	.005	.003	.001						
2	.043	.030	.020	.014	.006	.003	.001				
3	.112	.082	.059	.042	.021	.010	.002				
4	.224	.173	.132	.100	.055	.029	.008	.002			
5	.369	.301	.241	.191	.116	.067	.020	.006	.001		
6	.527	.450	.378	.313	.207	.130	.046	.014	.004	.001	
7	.673	.599	.525	.453	.324	.220	.090	.032	.010	.003	.001
8	.792	.729	.662	.593	.456	.333	.155	.062	.022	.007	.002
9	.877	.830	.776	.717	.587	.458	.242	.109	.043	.015	.005
10	.933	.901	.862	.816	.706	.583	.347	.176	.077	.030	.011
11	.966	.947	.921	.888	.803	.697	.462	.260	.127	.055	.021
12	.984	.973	.957	.936	.876	.792	.576	.358	.193	.092	.039
13	.993	.987	.978	.966	.926	.864	.682	.464	.275	.143	.066
14	.997	.994	.990	.983	.959	.917	.772	.570	.368	.208	.105
15	.999	.998	.995	.992	.978	.951	.844	.669	.467	.287	.157
16	1.000	.999	.998	.996	.989	.973	.899	.756	.566	.375	.221
17		1.000	.999	.998	.995	.986	.937	.827	.659	.469	.297
18			1.000	.999	.998	.993	.963	.883	.742	.562	.381
19				1.000	.999	.997	.979	.923	.812	.651	.470
20					1.000	.998	.988	.952	.868	.731	.559
21						.999	.994	.971	.911	.799	.644
22						1.000	.997	.983	.942	.855	.721
23							.999	.991	.963	.899	.787
24							.999	.995	.978	.932	.843
25							1.000	.997	.987	.955	.888
26								.999	.993	.972	.922
27								.999	.996	.983	.948
28								1.000	.998	.990	.966
29									.999	.994	.978
30									.999	.997	.987
31									1.000	.998	.992
32										.999	.995
33										1.000	.997
34											.999
35											.999
36											1.000

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TABLE A.7 Factors for 3σ Control Charts

Observations in Sample, n	$\bar{X}$ Charts			S Charts						$\bar{R}$ Charts						
	Factors for Control Limits			Factors for Central Line		Factors for Control Limits				Factors for Central Line		Factors for Control Limits				
	A	A_2	A_3	c_4	$1/c_4$	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	1.2533	0	3.267	0	2.606	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	1.023	1.954	0.8862	1.1284	0	2.568	0	2.276	1.693	0.5907	0.888	0	4.358	0	2.574
4	1.500	0.729	1.628	0.9213	1.0854	0	2.266	0	2.088	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	0.577	1.427	0.9400	1.0638	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	1.0510	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	0.419	1.182	0.9594	1.0423	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.204	5.204	0.076	1.924
8	1.061	0.373	1.099	0.9650	1.0363	0.185	1.815	0.179	1.751	2.847	0.3512	0.820	0.388	5.306	0.136	1.864
9	1.000	0.337	1.032	0.9693	1.0317	0.239	1.761	0.232	1.707	2.970	0.3367	0.808	0.547	5.393	0.184	1.816
10	0.949	0.308	0.975	0.9727	1.0281	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.285	0.927	0.9754	1.0252	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.811	5.535	0.256	1.744
12	0.866	0.266	0.886	0.9776	1.0229	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.922	5.594	0.283	1.717
13	0.832	0.249	0.850	0.9794	1.0210	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.025	5.647	0.307	1.693
14	0.802	0.235	0.817	0.9810	1.0194	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.118	5.696	0.328	1.672
15	0.775	0.223	0.789	0.9823	1.0180	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.203	5.741	0.347	1.653
16	0.750	0.212	0.763	0.9835	1.0168	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.282	5.782	0.363	1.637
17	0.728	0.203	0.739	0.9845	1.0157	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.356	5.820	0.378	1.622
18	0.707	0.194	0.718	0.9854	1.0148	0.482	1.518	0.475	1.496	3.640	0.2747	0.739	1.424	5.856	0.391	1.608
19	0.688	0.187	0.698	0.9862	1.0140	0.497	1.503	0.490	1.483	3.689	0.2711	0.734	1.487	5.891	0.403	1.597
20	0.671	0.180	0.680	0.9869	1.0133	0.510	1.490	0.504	1.470	3.735	0.2677	0.729	1.549	5.921	0.415	1.585
21	0.655	0.173	0.663	0.9876	1.0126	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.605	5.951	0.425	1.575
22	0.640	0.167	0.647	0.9882	1.0119	0.534	1.466	0.528	1.448	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.162	0.633	0.9887	1.0114	0.545	1.455	0.539	1.438	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.157	0.619	0.9892	1.0109	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.759	6.031	0.451	1.548
25	0.600	0.153	0.606	0.9896	1.0105	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.806	6.056	0.459	1.541

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INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR
Department of Industrial and Systems Engineering
Mid Autumn Semester Examination, 2016
Third Year B.Tech.(H)/Dual Degree in IM, QE, QM and MF

Subject Number: IM31005 **Subject Name**: Quality Design and Control
Full Marks: 60 **Time:** 2 Hours
Date, Time, and Venue of Examination: 20.09.2016, 14.00-16.00, F232/NC141/NR321/322
Number of Students Appearing in the Examination: 66

Instructions : 1. **Attempt all questions.**
2. Maximum marks are shown against each question.
3. Answers should be short and to the point.
4. Statistical and other tables as required are attached with the question paper.

Q.1 (a) Identify the elements of 'Quality Loop'. How is inspection-based QC different from QA? Briefly explain citing suitable examples. **(2 + 2)**

(b) How would you measure variability in a quality characteristic? State the construction and use of 'stem-and-leaf plot' and 'Box plot' in this context. **(1 + 2 + 2)**

(c) $\bar{x}$ and R charts with n = 4 are used to monitor a normally distributed quality characteristic. The control chart parameters are

$\bar{x}$ **Chart**	**R Chart**
UCL = 815	UCL = 46.98
Centre Line = 800	Centre Line = 20.59
LCL = 785	LCL = 0

Both charts exhibit control. What is the probability that a shift in the process mean to 790 will be detected on the first sample following the shift? Consider the $\bar{x}$ Chart and find the average run length for the chart. **(4 + 2)**

Q.2 (a) A control chart for fraction nonconforming indicates that the current process average is 0.03. The sample size is constant at 200 units.
(i) Find the three-sigma control limits for the control chart.
(ii) What is the probability that a shift in the process average to 0.08 will be detected on the first subsequent sample? What is the probability that this shift will be detected at least by the fourth sample following the shift? **(1 + 1.5 + 1.5)**

(b) Why do you use U-control chart? What is its main limitation? **(1 + 1)**

PTO

(c) In designing a fraction nonconforming chart with centre line at $p = 0.10$ and 2.5-sigma control limits, what is the sample size required to yield a positive lower control limits? What is the value of n necessary to give a probability of 0.40 of detecting a shift in the process to 0.20? **(2.5 + 2.5)**

(d) Define Type-I and Type-II errors in control charting in terms of hypothesis testing. Derive the control limits for standardized R-control chart. **(2 + 2)**

Q.3 (a) The data that follow are temperature readings from a chemical process in °C, taken every 2 minutes.

953	985	949	937	959	948	958	952
945	973	941	946	939	937	955	931
972	955	966	954	948	955	947	928
945	950	966	935	958	927	941	937
975	948	934	941	963	940	938	950
970	957	937	933	973	962	945	970
959	940	946	960	949	963	963	933
973	933	952	968	942	943	967	960
940	965	935	959	965	950	969	934
936	973	941	956	962	938	981	927

The target value for the mean is $\mu_0 = 950$.

(i) Estimate the process standard deviation.

(ii) Set up and apply a 'tabular cusum' for this process, using standardized values $h = 5$ and $k = 0.5$. Interpret this chart. **(2 + 7)**

(b) How do you define and measure 'gauge capability'? What is P/T ratio in this context? What is its limitation? Can you suggest an alternative measure for 'gauge capability' ratio? **(1 + 1 + 1 + 1)**

(c) What are the uses of C&E Diagram? **(2)**

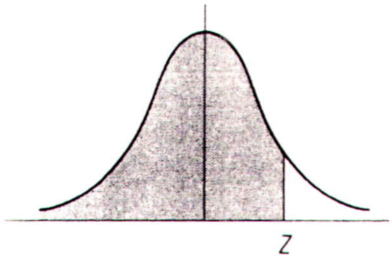
Q.4 (a) What are the principles of rational sub-grouping in control charting? Can you explain an industrial production scenario where these principles are followed? **(2 + 2)**

(b) State the possible assignable causes (maximum three) for each of the following control chart pattern in R-control chart: (i) mixture, (ii) trend, (iii) interaction. **(1.5 × 3 = 4.5)**

(c) Consider the two processes shown here (the sample size $n = 5$):

Process A	Process B
$\overline{\overline{x}}_A = 100$	$\overline{\overline{x}}_B = 105$
$\overline{S}_A = 3$	$\overline{S}_B = 1$

Specifications are at 100 ± 10. Calculate C_p, C_{pk}, and C_{pm} and interpret these ratios. Which process would you prefer to use? **(3 + 1 + 2.5)**



APPENDIX A-3 Cumulative Standard Normal Distribution

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
−3.40	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
−3.30	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
−3.20	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
−3.10	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
−3.00	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
−2.90	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
−2.80	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
−2.70	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
−2.60	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
−2.50	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
−2.40	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
−2.30	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
−2.20	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
−2.10	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
−2.00	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
−1.90	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
−1.80	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
−1.70	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
−1.60	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
−1.50	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
−1.40	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
−1.30	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
−1.20	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
−1.10	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
−1.00	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
−.90	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
−.80	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
−.70	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
−.60	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
−.50	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
−.40	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
−.30	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
−.20	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
−.10	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
−.00	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

Source: J. Banks and R. G. Meikes, *Handbook of Tables and Graphs for the Industrial Engineer and Manager,* © 1984, pp. 44–45. Reprinted by permission of Prentice Hall, Upper Saddle River, N.J.

APPENDIX A-3 *(cont.)*

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.00	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.10	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.20	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6046	.6103	.6141
.30	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.40	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.50	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.60	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.70	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.80	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.90	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.00	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.10	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.20	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.30	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.40	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.50	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.60	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.70	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.80	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.90	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.00	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.10	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.20	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.30	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.40	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.50	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.60	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.70	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.80	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.90	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.00	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.10	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.20	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.30	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997

Z	F(z)	Z	F(z)	Z	F(z)
3.50	.99976 73709	4.00	.99996 83288	4.50	.99999 66023
3.55	.99980 73844	4.05	.99997 43912	4.55	.99999 73177
3.60	.99984 08914	4.10	.99997 93425	4.60	.99999 78875
3.65	.99986 88798	4.15	.99998 33762	4.65	.99999 83403
3.70	.99989 22003	4.20	.99998 66543	4.70	.99999 86992
3.75	.99991 15827	4.25	.99998 93115	4.75	.99999 89829
3.80	.99992 76520	4.30	.99999 14601	4.80	.99999 92067
3.85	.99994 09411	4.35	.99999 31931	4.85	.99999 03827
3.90	.99995 19037	4.40	.99999 45875	4.90	.99999 95208
3.95	.99996 09244	4.45	.99999 57065	4.95	.99999 96289

APPENDIX A-7 Factors for Computing Center Line and Three-Sigma Control Limits

Observations in Sample, n	$\bar{X}$-Charts			s-Charts						R-Charts						
	Factors for Control Limits			*Factors for Center Line*		*Factors for Control Limits*				*Factors for Center Line*		*Factors for Control Limits*				
	A	A_2	A_3	c_4	$1/c_4$	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	1.2533	0	3.267	0	2.606	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	1.023	1.954	0.8862	1.1284	0	2.568	0	2.276	1.693	0.5907	0.888	0	4.358	0	2.574
4	1.500	0.729	1.628	0.9213	1.0854	0	2.266	0	2.088	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	0.577	1.427	0.9400	1.0638	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	1.0510	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	0.419	1.182	0.9594	1.0423	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.204	5.204	0.076	1.924
8	1.061	0.373	1.099	0.9650	1.0363	0.185	1.815	0.179	1.751	2.847	0.3512	0.820	0.388	5.306	0.136	1.864
9	1.000	0.337	1.032	0.9693	1.0317	0.239	1.761	0.232	1.707	2.970	0.3367	0.808	0.547	5.393	0.184	1.816
10	0.949	0.308	0.975	0.9727	1.0281	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.285	0.927	0.9754	1.0252	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.811	5.535	0.256	1.744
12	0.866	0.266	0.886	0.9776	1.0229	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.922	5.594	0.283	1.717
13	0.832	0.249	0.850	0.9794	1.0210	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.025	5.647	0.307	1.693
14	0.802	0.235	0.817	0.9810	1.0194	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.118	5.696	0.328	1.672
15	0.775	0.223	0.789	0.9823	1.0180	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.203	5.741	0.347	1.653
16	0.750	0.212	0.763	0.9835	1.0168	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.282	5.782	0.363	1.637
17	0.728	0.203	0.739	0.9845	1.0157	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.356	5.820	0.378	1.622
18	0.707	0.194	0.718	0.9854	1.0148	0.482	1.518	0.475	1.496	3.640	0.2747	0.739	1.424	5.856	0.391	1.608
19	0.688	0.187	0.698	0.9862	1.0140	0.497	1.503	0.490	1.483	3.689	0.2711	0.734	1.487	5.891	0.403	1.597
20	0.671	0.180	0.680	0.9869	1.0133	0.510	1.490	0.504	1.470	3.735	0.2677	0.729	1.549	5.921	0.415	1.585
21	0.655	0.173	0.663	0.9876	1.0126	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.605	5.951	0.425	1.575
22	0.640	0.167	0.647	0.9882	1.0119	0.534	1.466	0.528	1.448	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.162	0.633	0.9887	1.0114	0.545	1.455	0.539	1.438	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.157	0.619	0.9892	1.0109	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.759	6.031	0.451	1.548
25	0.600	0.153	0.606	0.9896	1.0105	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.806	6.056	0.459	1.541

Source:

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR
Department of Industrial and Systems Engineering
Mid Autumn Semester Examination, 2015
Third Year BTech.(H)/Dual Degree in IM, QE and QM

Subject Number: IM31005 **Subject Name:** Quality Design and Control
Full Marks: 60 **Time:** 2 Hours
Date, Time, and Venue of Examination: 21.09.2015, 14.00-16.00: F232/S302/NR221/NR322
Number of Students appearing in the Examination: 46

Instructions : 1. Attempt any two from Group-A and any two from Group-B
2. Maximum marks are shown against each question.
3. Answers should be short and to the point.
4. Statistical and other tables as required are attached with the Question Paper.

Group-A

Q.1 (a) Briefly describe the concept of Quality of Design, Quality of Conformance, and Quality of Performance. Why and how are they interdependent? What is 'implied quality' of a product? (3 + 2 + 1)

(b) The following fraction nonconforming control chart with n = 100 is used to control a process: UCL = 0.0750, CL = 0.0400 and LCL = 0.0050.

(i) Use Poisson approximation to Binomial to find the probability of a Type-I error.
(ii) Use Poisson approximation to Binomial to find the probability of a Type-II error, if the true process fraction nonconforming is 0.0600.
(iii) Draw the OC curve for this control chart.
(iv) Find the ARL when the process is in control and the ARL when the process fraction nonconforming is 0.0600. (2 + 2 + 3 + 2)

Q.2 (a) Why is control of process variability always a problem? State any three measures with which you may control process variability. What is the meaning of 'process mean' and what is its physical significance?
(1 + 1.5 + 0.5 + 1)

(b) A quality control characteristic is being monitored, using a 3-sigma control chart for X-bar. What is the probability that the first observation is within ± σ of the CL, the second observation is between zero and 2σ of the CL, and the third observation is out of control? **(3)**

(c) (i) Under what conditions, you may opt for X-chart? **(2)**

(ii) The deviations from the standard for Brinell Hardness Numbers (BHN) of the last 15 cupolas of iron produced at a local smelter are as follows:

Cupola	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Variation from Standard	9	-3	-3	-10	-5	7	1	-1	11	-4	0	2	1	5	8

Set up the moving range and individual control charts. **(6)**

Q.3 (a) Explain briefly the concept of 'Quality Loop'. What are the basic conditions to satisfy for implementing QA in a manufacturing system? (3 + 1)

(b) Interpret $C_{pk} \geq 1.67$ for a process. How are C_p, C_{pk} and C_{pm} interlinked? (2 + 2)

(c) Light bulbs are tested for their luminance, with the intensity of brightness desired to be within a certain range. Random samples of 5 bulbs are chosen from the output and their luminance values measured. The sample mean and range are found. After 30 samples, the following summary information is obtained:

$$\sum_{i=1}^{30} \bar{X}_i = 2550 \qquad \sum_{i=1}^{30} R_i = 195$$

The specifications are 90 ± 15 lumens.

(i) Find the control limits for R- and X-bar charts. (2)
(ii) Assuming that the process is in control, estimate the process mean and process standard deviation. (2)
(iii) Find the process capability indices C_p and C_{pk}, and comment on their values. (1)
(iv) If the target value is 90 lumens, find the capability index C_{pm}. (1)
(v) What proportion of the output is nonconforming, assuming a normal distribution of the quality characteristic? (1)

Group-B

Q.4 (a) Explain Type-A and Type-B OC curves .Write down the exact and approximate expressions for Type-A and Type-B OC functions. Define AQL, LTPD, producer's risk, and consumer's risk. (3 + 3 + 2)

(b) Given AQL = 1%, LTPD = 8%, $\alpha = 0.05$ and $\beta = 0.10$, find the values of n and c of a single sampling plan for a large lot. Use the following table. $[G(c, m_p) = p]$ (7)

c	0	1	2	3	4	5	6
$m_{0.95}$	0.051	0.355	0.818	1.366	1.970	2.613	3.285
$m_{0.10}$	2.30	3.89	5.32	6.68	7.99	9.28	10.53

Q.5 (a) Define AOQ. If at $p = p_1$, AOQ becomes maximum and $np_1 = x$. Derive the equation for obtaining x as a function of acceptance number c. (8)

(b) Given AOQL = 1.5%, lot size = 5000, find a single sampling plan which minimize ATI at process average of 1%. Use the following Table. (7)

c	2	3	4	5	6	7	8
y	1.371	1.942	2.544	3.168	3.812	4.472	5.146

Q.6 (a) Show that the binomial OC is a decreasing function of p and n. (8)

(b) Obtain the probability of acceptance for a double sampling plan with parameters $(n_1, n_2, c_1, c_2, c_3)$: (50, 50, 1, 2, 3) for large lots. Also obtain the ASN at p = 1%. (7)

APPENDIX A-2 Cumulative Poisson Distribution

λ = *Mean*

X	.01	.05	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	.990	.951	.905	.819	.741	.670	.607	.549	.497	.449	.407
1	1.000	.999	.995	.982	.963	.938	.910	.878	.844	.809	.772
2		1.000	1.000	.999	.996	.992	.986	.977	.966	.953	.937
3				1.000	1.000	.999	.998	.997	.994	.991	.987
4						1.000	1.000	1.000	.999	.999	.998
5									1.000	1.000	1.000

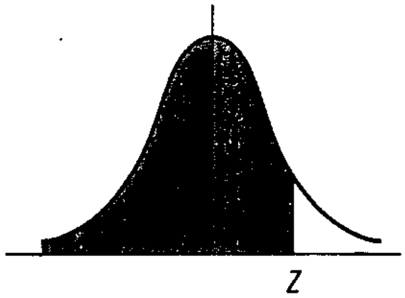
X	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0	.368	.333	.301	.273	.247	.223	.202	.183	.165	.150	.135
1	.736	.699	.663	.627	.592	.558	.525	.493	.463	.434	.406
2	.920	.900	.879	.857	.833	.809	.783	.757	.731	.704	.677
3	.981	.974	.966	.957	.946	.934	.921	.907	.891	.875	.857
4	.996	.995	.992	.989	.986	.981	.976	.970	.964	.956	.947
5	.999	.999	.998	.998	.997	.996	.994	.992	.990	.987	.983
6	1.000	1.000	1.000	1.000	.999	.999	.999	.998	.997	.997	.995
7					1.000	1.000	1.000	1.000	.999	.999	.999
8									1.000	1.000	1.000

X	2.2	2.4	2.6	2.8	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0	.111	.091	.074	.061	.050	.030	.018	.011	.007	.004	.002
1	.355	.308	.267	.231	.199	.136	.092	.061	.040	.027	.017
2	.623	.570	.518	.469	.423	.321	.238	.174	.125	.088	.062
3	.819	.779	.736	.692	.647	.537	.433	.342	.265	.202	.151
4	.928	.904	.877	.848	.815	.725	.629	.532	.440	.358	.285
5	.975	.964	.951	.935	.916	.858	.785	.703	.616	.529	.446
6	.993	.988	.983	.976	.966	.935	.889	.831	.762	.686	.606
7	.998	.997	.995	.992	.988	.973	.949	.913	.867	.809	.744
8	1.000	.999	.999	.998	.996	.990	.979	.960	.932	.894	.847
9		1.000	1.000	.999	.999	.997	.992	.983	.968	.946	.916
0				1.000	1.000	.999	.997	.993	.986	.975	.957
1						1.000	.999	.998	.995	.989	.980
2							1.000	.999	.998	.996	.991
3								1.000	.999	.998	.996
4									1.000	.999	.999
5										1.000	.999
6											1.000

ource: J. Banks and R. G. Meikes, *Handbook of Tables and Graphs for the Industrial Engineer and Manager,*

APPENDIX A-2 *(cont.)*

	λ = *Mean*										
X	*6.5*	*7.0*	*7.5*	*8.0*	*9.0*	*10.0*	*12.0*	*14.0*	*16.0*	*18.0*	*20.0*
0	.002	.001	.001								
1	.011	.007	.005	.003	.001						
2	.043	.030	.020	.014	.006	.003	.001				
3	.112	.082	.059	.042	.021	.010	.002				
4	.224	.173	.132	.100	.055	.029	.008	.002			
5	.369	.301	.241	.191	.116	.067	.020	.006	.001		
6	.527	.450	.378	.313	.207	.130	.046	.014	.004	.001	
7	.673	.599	.525	.453	.324	.220	.090	.032	.010	.003	.001
8	.792	.729	.662	.593	.456	.333	.155	.062	.022	.007	.002
9	.877	.830	.776	.717	.587	.458	.242	.109	.043	.015	.005
10	.933	.901	.862	.816	.706	.583	.347	.176	.077	.030	.011
11	.966	.947	.921	.888	.803	.697	.462	.260	.127	.055	.021
12	.984	.973	.957	.936	.876	.792	.576	.358	.193	.092	.039
13	.993	.987	.978	.966	.926	.864	.682	.464	.275	.143	.066
14	.997	.994	.990	.983	.959	.917	.772	.570	.368	.208	.105
15	.999	.998	.995	.992	.978	.951	.844	.669	.467	.287	.157
16	1.000	.999	.998	.996	.989	.973	.899	.756	.566	.375	.221
17		1.000	.999	.998	.995	.986	.937	.827	.659	.469	.297
18			1.000	.999	.998	.993	.963	.883	.742	.562	.381
19				1.000	.999	.997	.979	.923	.812	.651	.470
20					1.000	.998	.988	.952	.868	.731	.559
21						.999	.994	.971	.911	.799	.644
22						1.000	.997	.983	.942	.855	.721
23							.999	.991	.963	.899	.787
24							.999	.995	.978	.932	.843
25							1.000	.997	.987	.955	.888
26								.999	.993	.972	.922
27								.999	.996	.983	.948
28								1.000	.998	.990	.966
29									.999	.994	.978
30									.999	.997	.987
31									1.000	.998	.992
32										.999	.995
33										1.000	.997
34											.999
35											.999
36											1.000



APPENDIX A-3 Cumulative Standard Normal Distribution

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-3.40	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
-3.30	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
-3.20	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
-3.10	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
-3.00	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
-2.90	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
-2.80	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
-2.70	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
-2.60	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
-2.50	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
-2.40	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
-2.30	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
-2.20	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
-2.10	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
-2.00	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
-1.90	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
-1.80	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
-1.70	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
-1.60	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
-1.50	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
-1.40	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
-1.30	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
-1.20	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
-1.10	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
-1.00	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
-.90	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
-.80	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
-.70	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
-.60	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
-.50	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
-.40	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
-.30	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
-.20	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
-.10	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
-.00	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

Source: J. Banks and R. G. Meikes, *Handbook of Tables and Graphs for the Industrial Engineer and Manager,* © 1984, pp. 44–45. Reprinted by permission of Prentice Hall, Upper Saddle River, N.J.

APPENDIX A-3 *(cont.)*

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.00	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.10	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.20	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6046	.6103	.6141
.30	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.40	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.50	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.60	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.70	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.80	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.90	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.00	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.10	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.20	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.30	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.40	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.50	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.60	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.70	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.80	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.90	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.00	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.10	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.20	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.30	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.40	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.50	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.60	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.70	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.80	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.90	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.00	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.10	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.20	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.30	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997

Z	F(z)	Z	F(z)	Z	F(z)
3.50	.99976 73709	4.00	.99996 83288	4.50	.99999 66023
3.55	.99980 73844	4.05	.99997 43912	4.55	.99999 73177
3.60	.99984 08914	4.10	.99997 93425	4.60	.99999 78875
3.65	.99986 88798	4.15	.99998 33762	4.65	.99999 83403
3.70	.99989 22003	4.20	.99998 66543	4.70	.99999 86992
3.75	.99991 15827	4.25	.99998 93115	4.75	.99999 89829
3.80	.99992 76520	4.30	.99999 14601	4.80	.99999 92067
3.85	.99994 09411	4.35	.99999 31931	4.85	.99999 03827
3.90	.99995 19037	4.40	.99999 45875	4.90	.99999 95208
3.95	.99996 09244	4.45	.99999 57065	4.95	.99999 96289

APPENDIX A-7 Factors for Computing Center Line and Three-Sigma Control Limits

Observations in Sample, n	$\overline{X}$-Charts			s-Charts						R-Charts						
	Factors for Control Limits			Factors for Center Line		Factors for Control Limits				Factors for Center Line		Factors for Control Limits				
	A	A_2	A_3	c_4	$1/c_4$	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	1.2533	0	3.267	0	2.606	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	1.023	1.954	0.8862	1.1284	0	2.568	0	2.276	1.693	0.5907	0.888	0	4.358	0	2.574
4	1.500	0.729	1.628	0.9213	1.0854	0	2.266	0	2.088	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	0.577	1.427	0.9400	1.0638	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	1.0510	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	0.419	1.182	0.9594	1.0423	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.204	5.204	0.076	1.924
8	1.061	0.373	1.099	0.9650	1.0363	0.185	1.815	0.179	1.751	2.847	0.3512	0.820	0.388	5.306	0.136	1.864
9	1.000	0.337	1.032	0.9693	1.0317	0.239	1.761	0.232	1.707	2.970	0.3367	0.808	0.547	5.393	0.184	1.816
10	0.949	0.308	0.975	0.9727	1.0281	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.285	0.927	0.9754	1.0252	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.811	5.535	0.256	1.744
12	0.866	0.266	0.886	0.9776	1.0229	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.922	5.594	0.283	1.717
13	0.832	0.249	0.850	0.9794	1.0210	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.025	5.647	0.307	1.693
14	0.802	0.235	0.817	0.9810	1.0194	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.118	5.696	0.328	1.672
15	0.775	0.223	0.789	0.9823	1.0180	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.203	5.741	0.347	1.653
16	0.750	0.212	0.763	0.9835	1.0168	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.282	5.782	0.363	1.637
17	0.728	0.203	0.739	0.9845	1.0157	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.356	5.820	0.378	1.622
18	0.707	0.194	0.718	0.9854	1.0148	0.482	1.518	0.475	1.496	3.640	0.2747	0.739	1.424	5.856	0.391	1.608
19	0.688	0.187	0.698	0.9862	1.0140	0.497	1.503	0.490	1.483	3.689	0.2711	0.734	1.487	5.891	0.403	1.597
20	0.671	0.180	0.680	0.9869	1.0133	0.510	1.490	0.504	1.470	3.735	0.2677	0.729	1.549	5.921	0.415	1.585
21	0.655	0.173	0.663	0.9876	1.0126	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.605	5.951	0.425	1.575
22	0.640	0.167	0.647	0.9882	1.0119	0.534	1.466	0.528	1.448	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.162	0.633	0.9887	1.0114	0.545	1.455	0.539	1.438	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.157	0.619	0.9892	1.0109	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.759	6.031	0.451	1.548
25	0.600	0.153	0.606	0.9896	1.0105	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.806	6.056	0.459	1.541

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INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Department of Industrial Engineering and Management
Mid Autumn Semester Examination, 2012
Third Year B.Tech.(H)/Dual Degree in IM and EX

Subject Number: IM31005 **Subject Name:** Quality Design and Control
Full Marks: 60 **Time:** 2 Hours
Date, Time, and Venue of Examination: 25.09.2012, 14.00-16.00
Number of Students appearing in the Examination: 60

Instructions : 1. Attempt all questions.
2. Maximum marks are shown against each question.
3. Answers should be short and to the point.
4. Statistical and other tables as required are attached with the question paper.

Q.1 (a) Differentiate between 'quality control' and 'quality assurance'. How do you measure and assess the level of 'quality assurance' in a given work unit? How do you know that the products you produce are 'robust' in nature? **(2 + 2 + 2)**

(b) There may be many dimensions of quality. Given a manufactured product, state any three important dimensions of quality and their measures. How do you measure 'implied' quality of a product? **(3 + 1)**

(c) A pharmaceutical company producing vitamin capsules desires a proportion of calcium content between 40 and 55 ppm. A random sample of 20 capsules chosen from the output yields a sample mean calcium content of 44 ppm with a standard deviation of 3 ppm. Find the C_p index. Comment on the ability of the process to meet specifications. **(4 + 1)**

Q.2 (a) The specifications for a shift shaft are given by (0.490,0.510). Based on 40 samples of six shafts each, the R-chart indicates that the process is in control, with $\overline{\overline{X}} = 0.5031$ and $\overline{R} = 0.0141$.

(i) What is the $UCL_{\overline{X}}$ and $LCL_{\overline{X}}$? **(1)**

(ii) What is the fraction that can be expected to fall outside the specifications? **(2)**

(iii) What is the maximum function nonconforming that can be expected to fall outside the specifications if the process can be centered at any desired point, with no change in the standard deviation? **(2)**

(b) Why is Type-II error in control charting monitored and controlled? Define 'power' in this context. What sample size is needed to detect a negative shift of 1.5 standard deviations on the first sample following the shift in a control chart if the desired power is 0.75? **(1 + 1 + 5)**

(c) Derive the mathematical expression of β in terms of control limits, shift magnitude and sample size for an R-control chart. **(3)**

Q.3 (a) What is ARL curve in control charting? How is it affected by the control limits? **(1 + 1)**

PTO

(b) In a piston assembly, the specifications for the piston diameter are 12 ± 0.5 cm. and those for the cylinder diameter are 12.10 ± 0.4 cm. Assume that the natural tolerance limits coincide with the specifications. A clearance fit is required for the assembly. What proportion of the assemblies will be nonconforming, assuming a normal distribution of the piston and cylinder diameters? Clearances more than 0.8 cm are undesirable. What proportion of the assemblies will not meet this stipulation? **(4 + 3)**

(c) What is the advantage of using a 'standardized' control chart? How do you standardize an R-control chart? What is its limitation? **(1 + 4 + 1)**

Q.4 (a) Viscosity measurements on a polymer are made every 10 minutes by an on-line viscometer. Thirty-six observations are shown here (read down from left). The target viscosity for this process is $\mu_0 = 3200$.

3169	3205	3185	3188
3173	3203	3187	3183
3162	3209	3192	3175
3154	3208	3199	3174
3139	3211	3197	3171
3145	3214	3193	3180
3160	3215	3190	3179
3172	3209	3183	3175
3175	3203	3197	3174

(i) Estimate the process standard deviation. **(1)**

(ii) Construct a tabular cusum for this process using standardized values of h=8.01 and k=0.25. **(8)**

(iii) Discuss the choice of h and k in part (ii) of this problem on cusum performance. **(2)**

(b) The following data were taken by one operator during a gage capability study.

(i) Estimate gage capability. **(3)**

(ii) Does the control chart analysis of these data indicate any potential problem in using the gage? **(1)**

Part Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Measurement1	20	19	21	24	21	25	18	16	20	23	28	19	21	20	18
Measurement2	20	20	21	20	21	26	17	15	20	22	22	25	20	21	18

TABLE A.1 Cumulative Normal Distribution

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
−3.40	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
−3.30	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
−3.20	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
−3.10	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
−3.00	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
−2.90	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
−2.80	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
−2.70	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
−2.60	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
−2.50	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
−2.40	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
−2.30	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
−2.20	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
−2.10	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
−2.00	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
−1.90	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
−1.80	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
−1.70	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
−1.60	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
−1.50	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
−1.40	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
−1.30	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
−1.20	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
−1.10	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
−1.00	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
−.90	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
−.80	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
−.70	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
−.60	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
−.50	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
−.40	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
−.30	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
−.20	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
−.10	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
−.00	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

TABLE A.1 Cumulative Normal Distribution *continued*

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.00	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.10	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.20	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6046	.6103	.6141
.30	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.40	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.50	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.60	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.70	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.80	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.90	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.00	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.10	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.20	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.30	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.40	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.50	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.60	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.70	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.80	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.90	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.00	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.10	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.20	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.30	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.40	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.50	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.60	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.70	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.80	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.90	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.00	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.10	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.20	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.30	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997

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TABLE A.2 Cumulative Poisson Distribution

	λ = *Mean*										
X	*.01*	*.05*	*.1*	*.2*	*.3*	*.4*	*.5*	*.6*	*.7*	*.8*	*.9*
0	.990	.951	.905	.819	.741	.670	.607	.549	.497	.449	.407
1	1.000	.999	.995	.982	.963	.938	.910	.878	.844	.809	.772
2		1.000	1.000	.999	.996	.992	.986	.977	.966	.953	.937
3				1.000	1.000	.999	.998	.997	.994	.991	.987
4						1.000	1.000	1.000	.999	.999	.998
5									1.000	1.000	1.000

X	*1.0*	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*	*1.7*	*1.8*	*1.9*	*2.0*
0	.368	.333	.301	.273	.247	.223	.202	.183	.165	.150	.135
1	.736	.699	.663	.627	.592	.558	.525	.493	.463	.434	.406
2	.920	.900	.879	.857	.833	.809	.783	.757	.731	.704	.677
3	.981	.974	.966	.957	.946	.934	.921	.907	.891	.875	.857
4	.996	.995	.992	.989	.986	.981	.976	.970	.964	.956	.947
5	.999	.999	.998	.998	.997	.996	.994	.992	.990	.987	.983
6	1.000	1.000	1.000	1.000	.999	.999	.999	.998	.997	.997	.995
7					1.000	1.000	1.000	1.000	.999	.999	.999
8									1.000	1.000	1.000

X	*2.2*	*2.4*	*2.6*	*2.8*	*3.0*	*3.5*	*4.0*	*4.5*	*5.0*	*5.5*	*6.0*
0	.111	.091	.074	.061	.050	.030	.018	.011	.007	.004	.002
1	.355	.308	.267	.231	.199	.136	.092	.061	.040	.027	.017
2	.623	.570	.518	.469	.423	.321	.238	.174	.125	.088	.062
3	.819	.779	.736	.692	.647	.537	.433	.342	.265	.202	.151
4	.928	.904	.877	.848	.815	.725	.629	.532	.440	.358	.285
5	.975	.964	.951	.935	.916	.858	.785	.703	.616	.529	.446
6	.993	.988	.983	.976	.966	.935	.889	.831	.762	.686	.606
7	.998	.997	.995	.992	.988	.973	.949	.913	.867	.809	.744
8	1.000	.999	.999	.998	.996	.990	.979	.960	.932	.894	.847
9		1.000	1.000	.999	.999	.997	.992	.983	.968	.946	.916
10				1.000	1.000	.999	.997	.993	.986	.975	.957
11						1.000	999	.998	.995	.989	.980
12							1.000	.999	.998	.996	.991
13								1.000	.999	.998	.996
14									1.000	.999	.999
15										1.000	.999
16											1.000

TABLE A.2 Cumulative Poisson Distribution *continued*

	λ = Mean										
X	*6.5*	*7.0*	*7.5*	*8.0*	*9.0*	*10.0*	*12.0*	*14.0*	*16.0*	*18.0*	*20.0*
0	.002	.001	.001								
1	.011	.007	.005	.003	.001						
2	.043	.030	.020	.014	.006	.003	.001				
3	.112	.082	.059	.042	.021	.010	.002				
4	.224	.173	.132	.100	.055	.029	.008	.002			
5	.369	.301	.241	.191	.116	.067	.020	.006	.001		
6	.527	.450	.378	.313	.207	.130	.046	.014	.004	.001	
7	.673	.599	.525	.453	.324	.220	.090	.032	.010	.003	.001
8	.792	.729	.662	.593	.456	.333	.155	.062	.022	.007	.002
9	.877	.830	.776	.717	.587	.458	.242	.109	.043	.015	.005
10	.933	.901	.862	.816	.706	.583	.347	.176	.077	.030	.011
11	.966	.947	.921	.888	.803	.697	.462	.260	.127	.055	.021
12	.984	.973	.957	.936	.876	.792	.576	.358	.193	.092	.039
13	.993	.987	.978	.966	.926	.864	.682	.464	.275	.143	.066
14	.997	.994	.990	.983	.959	.917	.772	.570	.368	.208	.105
15	.999	.998	.995	.992	.978	.951	.844	.669	.467	.287	.157
16	1.000	.999	.998	.996	.989	.973	.899	.756	.566	.375	.221
17		1.000	.999	.998	.995	.986	.937	.827	.659	.469	.297
18			1.000	.999	.998	.993	.963	.883	.742	.562	.381
19				1.000	.999	.997	.979	.923	.812	.651	.470
20					1.000	.998	.988	.952	.868	.731	.559
21						.999	.994	.971	.911	.799	.644
22						1.000	.997	.983	.942	.855	.721
23							.999	.991	.963	.899	.787
24							.999	.995	.978	.932	.843
25							1.000	.997	.987	.955	.888
26								.999	.993	.972	.922
27								.999	.996	.983	.948
28								1.000	.998	.990	.966
29									.999	.994	.978
30									.999	.997	.987
31									1.000	.998	.992
32										.999	.995
33										1.000	.997
34											.999
35											.999
36											1.000

Source: J. Banks/R. G. Heikes, *Handbook of Tables and Graphs for the Industrial Engineer and Manager*, © 1984, pp. 34–35 (A Reston Publication). Reprinted by permission of Prentice-Hall, Englewood Cliffs, New Jersey.

TABLE A.7 Factors for 3σ Control Charts

Observations in Sample, n	$\overline{X}$ Charts			S Charts						R Charts						
	Factors for Control Limits			Factors for Central Line		Factors for Control Limits				Factors for Central Line		Factors for Control Limits				
	A	A_2	A_3	c_4	$1/c_4$	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	1.2533	0	3.267	0	2.606	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	1.023	1.954	0.8862	1.1284	0	2.568	0	2.276	1.693	0.5907	0.888	0	4.358	0	2.574
4	1.500	0.729	1.628	0.9213	1.0854	0	2.266	0	2.088	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	0.577	1.427	0.9400	1.0638	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	1.0510	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	0.419	1.182	0.9594	1.0423	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.204	5.204	0.076	1.924
8	1.061	0.373	1.099	0.9650	1.0363	0.185	1.815	0.179	1.751	2.847	0.3512	0.820	0.388	5.306	0.136	1.864
9	1.000	0.337	1.032	0.9693	1.0317	0.239	1.761	0.232	1.707	2.970	0.3367	0.808	0.547	5.393	0.184	1.816
10	0.949	0.308	0.975	0.9727	1.0281	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.285	0.927	0.9754	1.0252	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.811	5.535	0.256	1.744
12	0.866	0.266	0.886	0.9776	1.0229	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.922	5.594	0.283	1.717
13	0.832	0.249	0.850	0.9794	1.0210	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.025	5.647	0.307	1.693
14	0.802	0.235	0.817	0.9810	1.0194	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.118	5.696	0.328	1.672
15	0.775	0.223	0.789	0.9823	1.0180	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.203	5.741	0.347	1.653
16	0.750	0.212	0.763	0.9835	1.0168	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.282	5.782	0.363	1.637
17	0.728	0.203	0.739	0.9845	1.0157	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.356	5.820	0.378	1.622
18	0.707	0.194	0.718	0.9854	1.0148	0.482	1.518	0.475	1.496	3.640	0.2747	0.739	1.424	5.856	0.391	1.608
19	0.688	0.187	0.698	0.9862	1.0140	0.497	1.503	0.490	1.483	3.689	0.2711	0.734	1.487	5.891	0.403	1.597
20	0.671	0.180	0.680	0.9869	1.0133	0.510	1.490	0.504	1.470	3.735	0.2677	0.729	1.549	5.921	0.415	1.585
21	0.655	0.173	0.663	0.9876	1.0126	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.605	5.951	0.425	1.575
22	0.640	0.167	0.647	0.9882	1.0119	0.534	1.466	0.528	1.448	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.162	0.633	0.9887	1.0114	0.545	1.455	0.539	1.438	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.157	0.619	0.9892	1.0109	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.759	6.031	0.451	1.548
25	0.600	0.153	0.606	0.9896	1.0105	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.806	6.056	0.459	1.541

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INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

Department of Industrial Engineering and Management
Mid Autumn Semester Examination, 2011
Third Year/Fourth Year B.Tech.(H)/Dual Degree in IM and MF

Subject Number: IM31005 **Subject Name:** Quality Design and Control
Full Marks: 60 **Time:** 2 Hours
Date, Time, and Venue of Examination: 26.09.2011, 14.00-16.00, V1 & V3
Number of Students appearing in the Examination: 54

Instructions : 1. **Attempt all questions.**
2. Maximum marks are shown against each question.
3. Answers should be short and to the point.
4. Statistical and other tables as required are attached with the question paper.

Q.1 (a) Definition of 'quality' varies from one 'product' or 'situation' to another. Why? What do you mean by 'implied' quality of a system? Identify the elements of 'quality' loop. **(2 + 1 + 2)**

(b) State any four characteristic features of **(2 + 2)**

(i) an in-control process, and
(ii) an out-of-control process.

'Interaction' and 'Wild' patterns in control charting are due to the existence of 'special' causes. Identify two such causes for each. **(1 + 1)**

(c) For a normally distributed quality characteristic, the control chart has three-sigma control limits and the sample size is 5. If one or more of the next seven samples yield values of the sample averages that fall outside the control limits, conclude that the process is out of control. What is the Type-I error probability associated with this rule? **(4)**

Q.2 (a) The following data were obtained when measurements were made on the diameter of steel balls for use in bearings. The mean and range values of 16 samples of size 5 are given the table below.

Sample Number	Mean Dia. (0.001 mm)	Sample Range (mm)	Sample Number	Mean Dia. (0.001 mm)	Sample Range (mm)
1	250.2	0.005	9	250.4	0.004
2	251.3	0.005	10	250.0	0.004
3	250.4	0.005	11	249.4	0.0045
4	250.2	0.003	12	249.8	0.0035
5	250.7	0.004	13	249.3	0.0045
6	248.9	0.004	14	249.1	0.0035
7	250.2	0.005	15	251.0	0.004
8	249.1	0.004	16	250.6	0.0045

PTO

Design a mean cusum chart for the process, plot the results on the chart and interpret them. (5)
What is a V-mask template? How is it used? (2 + 2)

(b) State the principles of rational subgrouping used in a control chart. State also the Central Limit Theorem and briefly explain (in two sentences only) its importance in SPC. (2 + 2 + 2)

Q.3 (a) Samples are being taken from a pin manufacturing process every 15-20 minutes. The production rate is 350-400 per hour, and the specification limits on length are 0.820 and 0.840 cm. After 20 samples of 5 pins, the following information is available:

Sum of the sample means: 16.68
Sum of the sample ranges: 0.14 cm

(i) Set up mean and range charts to control the lengths of pins produced in the future. (3.5)
(ii) If the pin lengths are normally distributed, what proportion of the pins would you estimate to have lengths outside the specification limits when the process is under control at the levels indicated by the data given? (1.5)
(iii) What would happen to the proportion of defective pins if the process average changed to 0.837? (1.5)
(iv) What is the probability that you could observe the change in (iii) on your control chart on the first sample following the change? (1.5)

(b) Define C_p and C_{pk} indices and briefly explain how they may be used to monitor capability of a process. A process is declared as 'in statistical control' but 'not capable'. What does it signify? (3 + 2 + 2)

Q.4 (a) Define 'repeatability' and 'reproducibility' in the context of gauge capability measurement. What are the possible action steps that may be required for improving gauge capability? (1.5 x 2 + 2)

(b) U-control chart is constructed and used in a special situation. What is it? Is this control chart a reliable one? Why or why not? (1 + 2)

(c) Distinguish between: (1 + 2 + 2)

(i) Natural and statistical tolerance limits
(ii) Clearance and interference fits
(iii) Modified and acceptance control charts

(d) What is a Box plot? Explain it with just two sentences. (2)

INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR
Department of Industrial Engineering and Management
Mid Autumn Semester Examination, 2010
Third Year/Fourth Year B.Tech.(H)/Dual Degree in IM and MF

Subject Number: IM31005 **Subject Name:** Quality Design and Control
Full Marks: 60 **Time:** 2 Hours
Date, Time, and Venue of Examination: 14.09.2010, 14.00-16.00, F-116
Number of Students appearing in the Examination: 46

Instructions : 1. Attempt all questions.
2. Maximum marks are shown against each question.
3. Answers should be short and to the point.
4. Statistical and other tables as required are attached with the question paper.

Q.1 (a) What is meant by the statement that a process is in a state of statistical control? (2)
(b) What are 'warning' limits on a control chart? How can they be used? (2 + 2)
(c) When taking samples from a process, do you want assignable causes occurring within the samples or between them? Fully explain your answer. (3)
(d) What information does ARL convey that the type-I and type-II error probabilities do not? (2)
(e) You consistently arrive at your classroom about fifteen minutes later than you would like. Develop a cause-and-effect diagram that identifies and outlines the possible causes of this event. (4)

Q.2 (a) Samples of size n = 5 are taken from a manufacturing process every hour. A quality characteristic is measured, and X-bar and R are computed for each sample. After 25 samples have been analyzed, we have totals of X-bar and R are 662.50 and 9.00, respectively. The quality characteristic is normally distributed.

(i) Find the three-sigma control limits for X-bar and R charts. (3)
(ii) Assume that both charts exhibit control. If the specifications are 26.40 ± 0.50, estimate the fraction nonconforming. (3)
(iii) If the mean of the process were 26.40, what fraction nonconforming would result? (2)

(b) Define 'repeatability' and 'reproducibility' of the gauge. What procedure you employ to measure and interpret them? What is the measure of gauge capability you suggest and why? (2 + 3 + 2)

Q.3 (a) In designing a fraction nonconforming chart with centre line at p = 0.20 and three-sigma control limits, what is the sample size required to yield a positive lower control limit? What is the value of n necessary to give a probability of 0.50 of detecting a shift in the process to 0.26? (2 + 3)

(PTO)

(b) Derive the mathematical expressions of the control limits for both R- and $\bar{X}$-control charts when sample size is a variable. (3 + 3)

(c) State briefly the concepts of C_{pk} and C_{pm}. What is the main limitation of C_{pm}? (3 + 1)

Q.4 (a) Why do you design and use a Cusum control chart? Explain the Tabular Cusum for monitoring process mean. (2 + 5)

(b) Distinguish between quality of design and quality of conformance. Cite an example of interaction pattern in control charting. (2 + 2)

(c) Decreasing the process variability is always a serious concern for many processes. Why? (2)

(d) Why do you use a U-control chart? Write down its upper and lower control limits. (1 + 1)