UNIVERSITI SAINS MALAYSIA

Course Examination During Long Vacation
Academic Session 2008/2009
Peperiksaan Kursus Semasa Cuti Panjang
Sidang Akademik 2008/2009

June 2009
Jun 2009

EPM 332/3 – Quality & Reliability
Kualiti & Kebolehpercayaan

Duration : 3 hours
Masa : 3 jam

INSTRUCTIONS TO CANDIDATE :
ARAHAN KEPADA CALON :

Please check that this paper contains **TWELVE (12)** printed pages, and **FOUR (4)** page appendix and **FIVE (5)** questions before you begin answering the questions.
*Sila pastikan bahawa kertas soalan ini mengandungi **DUA BELAS (12)** mukasurat, **EMPAT (4)**) lampiran dan **LIMA (5)** soalan yang bercetak sebelum anda mula menjawab soalan.*

Answer **ALL** questions.
*Sila jawab **SEMUA** soalan.*

Answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.
*Calon boleh menjawab semua soalan dalam **Bahasa Inggeris** ATAU **Bahasa Malaysia** ATAU kombinasi kedua-duanya.*

Appendix/*Lampiran :*

Appendix 1/*Lampiran 1*	**[1] page**/*[1] mukasurat*
Appendix 1 (cont)/*Lampiran 1(sambungan)*	**[1] page**/*[1] mukasurat*
Appendix 2/*Lampiran 2*	**[1] page**/*[1] mukasurat*
Appendix 3/*Lampiran 3*	**[1] page**/*[1] mukasurat*

Answer to each question must begin from a new page.
Jawapan bagi setiap soalan mestilah dimulakan pada mukasurat yang baru.

Q1. In Mechanical Milling (MM) of metal or ceramic powders, coarse particulates are broken into ultimate fineness by means of mechanical impact generated by collisions between milling ball and internal surface of a reciprocating vial where metal or ceramic powders are trapped in between. Thus, in order to achieve a productive process, the number of effective collisions at the best configuration of process parameters should be determined. Thus:

[a] By using DOE, parameters relevant to the objective should be determined and the process variables should be analysed. In order to do so:

(i) Draw a flowchart of the steps to execute the DOE, starting from identification of the problem until the recommendation for improvement.

(ii) Discuss the relationships between each neighbouring steps including the identification and recommendation steps.

Di dalam pengisaran mekanikal (Mechanical Milling, MM) bagi serbuk logam atau serbuk seramik, partikel yang kasar dihancurkan sehingga halus dengan mengenakan impak mekanikal. Impak ini terhasil dari perlanggaran di antara bola pengisar dengan serbuk logam atau serbuk seramik terhadap permukaan dalam tabung. Pada perlanggaran tersebut serbuk logam atau serbuk seramik berada di antara bola pengisar dengan dinding dalam tabung. Perlanggaran ini terjadi disebabkan oleh gerak ke atas dan ke bawah daripada tabung yang mengandungi bola dan serbuk logam atau serbuk seramik tersebut. Oleh yang demikian, untuk mendapatkan proses yang produktif, bilangan perlanggaran yang efektif pada konfigurasi parameter proses yang terbaik perlu diperolehi. Untuk itu:

[a] Dengan menggunakan kaedah rekabentuk eksperimen (DOE), perlu dikenal pasti parameter yang sesuai untuk mencapai objektif dan perlu di analisa pembolehubah proses. Untuk itu:

(i) Lukiskan carta aliran bagi langkah-langkah yang diperlukan dalam menjalankan DOE, bermula dari mengenal pasti masalah sehingga cadangan untuk penambahbaikan.

(ii) Bincangkan perkaitan di antara setiap langkah yang berturutan berserta langkah pengenalpastian dan langkah perakuan.

(50 marks/*markah*)

[b] Table Q1[b] shows the numbers of effective collisions observed in the mechanical milling (MM) process.

(i) Using the data shown in Table Q1[b], develop an Analysis of Variance (ANOVA) table for an effective collision data based on 95% confidence level.

Calculate:
(i) the mean value for each levels
(ii) the sum of square for total
(iii) the sum of squares for the main effects
(iv) the sum of square for the interaction
(v) the sum of square for error

Jadual S1[b] menunjukkan bilangan perlanggaran efektif yang diperolehi ketika proses pengisaran mekanikal (MM) dijalankan.

(i) Menggunakan data yang ditunjukkan dalam Jadual S1[b], bina jadual analisa variasi (ANOVA) bagi data perlanggaran efektif berdasarkan 95% tahap kepercayaan.

Kirakan:
(i) nilai purata bagi setiap tahap
(ii) jumlah punca kuasa bagi keseluruhan
(iii) jumlah punca kuasa bagi kesan utama
(iv) jumlah punca kuasa bagi interaksi
(v) jumlah punca kuasa bagi ralat

Table Q1[b]: Number of Effective Collision Data for the MM Design Experiment
Jadual S1[b]: Data bilangan perlanggaran efektif bagi rekabentuk eksperimen di dalam proses pengisaran mekanikal

Speed (RPM) *Halaju (RPM)*	**Height (mm)** *Ketinggian (mm)*					
	100		150		200	
800	180	174	75	40	52	58
	130	155	80	55	70	82
1000	188	159	136	122	58	45
	150	126	106	115	75	70
1200	110	168	174	139	90	82
	160	138	150	120	96	104

(30 marks/*markah*)

(ii) **Construct an ANOVA table using the results obtained in (i), (ii), (iii), (iv), and (v) above and briefly discuss the results.**

Bina jadual ANOVA menggunakan jawapan yang diperolehi dari (i), (ii), (iii), (iv), and (v) di atas dan bincangkan dengan ringkas keputusan yang diperolehi.

(20 marks/*markah*)

Q2. [a] **Company ABC is an aluminium plate manufacturer. From a Failure Mode Effect Analysis (FMEA), the quality team identified that the potential failure of the product is the variation on the plate thickness. The cause of this variation is occurred at the rolling process. Thus, quality team decides to monitor the process. Control charts will be used to monitor the variation of the process. Table Q2[a] shows the data collected during production run. The rolling operator makes 15 observations of 5 sample size.**

Syarikat ABC merupakan pengeluar plat aluminium. Daripada analisis kesan mod kegagalan (FMEA), pasukan kualiti mengenalpasti bahawa potensi kegagalan bagi produk adalah berpunca daripada variasi ketebalan plat. Variasi yang berlaku berpunca daripada proses penggelekan. Oleh yang demikian, kumpulan kualiti menetapkan bahawa proses penggelekan tersebut perlu diawasi. Carta kawalan akan digunakan untuk mengawasi variasi proses tersebut. Jadual S2[a] menunjukkan data yang diperolehi semasa pengeluaran berjalan. Operator proses penggelekan melaksanakan 15 pemerhatian dengan 5 sempel setiap kalinya.

Table Q2[a]: Aluminium plate thickness (mm) recorded during production run
Jadual S2[a]: Rekod ketebalan (mm) plat aluminium ketika proses pengeluaran

Sample *Sampel*	**Observation** *Pemerhatian*														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.23	.27	.30	.25	.19	.24	.26	.24	.26	.25	.16	.21	.28	.25	.23
2	.30	.31	.28	.23	.20	.17	.23	.30	.26	.25	.18	.30	.19	.14	.29
3	.28	.23	.24	.21	.25	.18	.20	.15	.30	.25	.27	.22	.29	.27	.23
4	.29	.23	.32	.20	.26	.26	.27	.27	.24	.28	.21	.26	.26	.16	.27
5	.31	.29	.30	.30	.25	.18	.12	.21	.27	.31	.29	.24	.24	.28	.24

(i) **Based on the data in Table Q2[a], develop a chart to be used to control the tendencies of the data variation.**

Berdasarkan data di Jadual S2[a], binakan carta yang akan digunakan untuk mengetahui kecenderungan bagi variasi data.

(20 marks/*markah*)

(ii) **In order to know the subgroup dispersion of the thickness of the plate, develop a suitable chart to facilitate this requirement.**

Untuk mengetahui serakan kumpulan sampel bagi ketebalan plat, binakan carta yang sesuai.

(30 marks/*markah*)

[iii] **There are seven possible patterns that could be identified in control charts during the process monitoring. Discuss five of them.**

Terdapat tujuh corak yang boleh didapati di dalam sesuatu carta kawalan ketika proses pengawasan. Bincangkan lima daripadanya.

(20 marks/*markah*)

[b] **Sigma Plastic Sdn. Bhd. produces credit card blanks for a number of years. They use *p*-chart to keep track the fraction of nonconforming blanks that are created every day. The number of nonconforming blanks (*np*) is then recorded as shown in Table Q2[b]. 15,000 blank cards are produced each day. Every day, a sample of 500 units are randomly selected.**

By using data on Table Q2[b],

[i] **Create a fraction nonconforming chart that includes fraction of nonconforming for each day and allowable control limits.**

Selama beberapa tahun, Sigma Plastik Sdn. Bhd. menghasilkan kad kredit kosong. Setiap hari, syarikat ini menggunakan carta-p untuk mengenalpasti pecahan kad yang rosak. Bilangan kad rosak (np) kemudian direkod seperti terdapat di Jadual S2[b]. Setiap hari, bilangan kad kosong yang dihasilkan adalah sebanyak 15,000 unit. Setiap harinya 500 unit sampel dipilih secara rawak.

Dengan menggunakan data di Jadual S2[b],

Binakan carta pecahan kad rosak yang mengandungi nilai pecahan kad rosak bagi setiap hari dan nilai had kawalan yang dibenarkan.

(20 marks/*markah*)

[ii] Briefly discuss the results from fraction nonconforming chart.

Bincangkan dengan ringkas keputusan yang diperolehi daripada carta yang telah dibina.

Table Q2[b]: Number of non-conforming blanks (*np*)
Jadual S2[b]: Bilangan kad rosak ***(np)***

Day/*Hari*	***np***
1	21
2	18
3	20
4	19
5	19
6	18
7	11
8	10
9	9
10	10
11	11
12	28
13	17
14	20
15	9
16	8
17	20
18	19
19	15
20	10

(10 marks/*markah*)

Q3. **To manufacture a product, there are three stages involved: design stage, followed by fabrication stage, and finally inspection stage. Specifications are established in the design stage. During fabrication, physical attempts are made to conform to these specifications. Problems would occur during establishing and implementing the specifications, thus, product designers should have the capability to decide and calculate the appropriate specifications for any problem such as:**

Dalam menghasilkan sesuatu produk, terdapat tiga tahap yang terlibat: tahap rekabentuk, diikuti dengan pembuatan, diakhiri dengan pemeriksaan. Spesifikasi dibuat semasa tahap rekabentuk. Semasa pembuatan produk, usaha fizikal dilakukan bagi memastikan kesemua spesifikasi yang ditetapkan, diikuti. Masalah akan timbul ketika menghasilkan dan memasukkan spesifikasi yang ditetapkan. Oleh yang demikian, pereka produk perlu mempunyai kemampuan untuk menetapkan spesifikasi yang sesuai.

[a] **Commonly, there are conflicts that may occur between specification limits and fabrication facilities capability. Draw two relevant sketches of those conflicts and describe each one briefly including their appropriate corrective actions.**

Biasanya, akan timbul konflik di antara had spesifikasi dan keupayaan kelengkapan penghasilan. Buatkan dua lakaran yang bersesuaian bagi konflik-konflik tersebut dan huraikan dengan ringkas setiap satunya beserta tindakan pembetulan yang sesuai.

(30 marks/*markah*)

[b] **Figure Q3[b] shows an assembly of rotor shaft. The length of each component is normally distributed (μ, σ^2) as:**

Calculate:

(i) **the mean value for final assembly**

(ii) **the variance value for final assembly**

By using the results obtained in (i) and (ii), identify the percentage of the assemblies that will fall within the specification if the assembly length's specification is 110 ± 3.0.

Rajah S3[b] menunjukkan sambungan bagi syaf rotor. Panjang bagi setiap komponen menuruti taburan normal (μ, σ^2) *iaitu:*

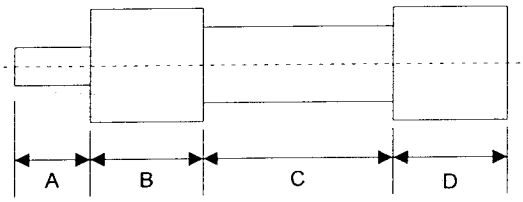

Figure Q3[b]: Rotor shaft
Rajah S3[b]: Syaf rotor

$A \sim N(23, 0.6)$
$B \sim N(26, 0.5)$
$C \sim N(34, 0.3)$
$D \sim N(26, 0.8)$

Kirakan:

(i) nilai purata bagi sambungan akhir
(ii) nilai variasi bagi sambungan akhir

Dengan menggunakan jawapan (i) dan (ii) di atas, dapatkan peratusan sambungan yang akan berada di dalam spesifikasi jika spesifikasi panjang sambungan adalah 110 ± 3.0.

(25 marks/*markah*)

[c] By using the assembly shown in Figure Q3[b], determine the specification limits for its component and assembly. Assume that the designer set the specification limits at $\pm 3\sigma$ from the mean.

Thus, calculate;

(i) specification limits of the assembly
(ii) tolerance range of the assembly specification limits
(iii) tolerance range for component A in the assembly
(iv) identify the tolerance ranges needed to be specified at each workstation if the tolerance range for the assembly is 7.0 mm. Assume that there are three workstations as shown in Table Q3[c].

Table Q3[c]: Workstations for assembly line
Jadual S3[c]: Stesen kerja bagi pemasangan.

Workstation *Stesen* kerja	**Assembled components** *Komponen yang dipasang*	**Results** Keputusan
1	A and B	AB
2	C and AB	ABC
3	D and ABC	ABCD

Use the PCR = 1, USL-LSL = 6σ.
Gunakan PCR = 1, USL-LSL = 6σ.

Dengan menggunakan pemasangan di Rajah S3[b], dapatkan had spesifikasi bagi komponen dan pemasangannya. Andaikan jurutera rekabentuk menetapkan had spesifikasi berlaku pada $\pm 3\sigma$ dari purata.

Oleh yang demikian, kirakan:
(i) had spesifikasi bagi pemasangan.
(ii) beza toleransi bagi had spesifikasi pemasangan.
(iii) beza toleransi bagi komponen A di dalam pemasangan.
(iv) kenalpasti beza toleransi yang diperlukan bagi setiap ruang kerja jika beza toleransi bagi pemasangan ialah 7.0 mm. Anggapkan terdapat tiga stesen kerja seperti yang di tunjukkan dalam Jadual S3[c].

(45 marks/*markah*)

Q4. Chain drive is used for an internal combustion engine to drive a centrifugal compressor. Components of the chain are shown in Figure Q4[a]. Some of the potential reliability problems associated with chain drives include:

(i) Chain drives can elongate due to wearing of link and sprocket teeth contact surfaces
(ii) Sprockets need to be replaced whenever worn chains are replaced because of wear

Rantai penjana digunakan bagi enjin pembakaran dalam untuk menjana pemampatan empar (centrifugal compressor). Bahagian-bahagian daripada rantai penjana ditunjukkan pada Rajah S4[a]. Beberapa potensi masalah kebolehpercayaan rantai penjana adalah berkenaan hal-hal seperti berikut:

(i) Rantai penjana akan memanjang disebabkan oleh kehausan sambungan rantai dan juga permukaan sentuh gigi sproket.
(ii) Sproket perlu ditukar apabila rantai yang rosak diganti kerana haus.

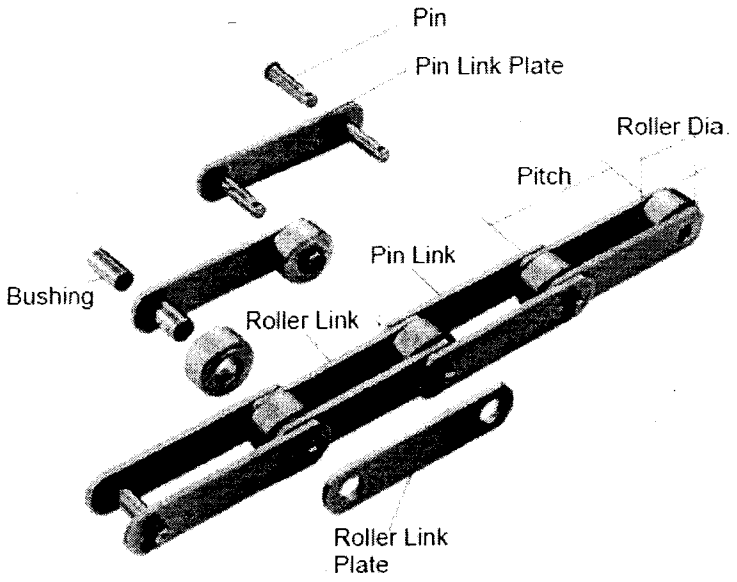

Figure Q4[a]: Components of chain drive
Rajah S4[a]: Bahagia-bahagian bagi rantai penjana

[a] **Develop a typical table of FMEA for the chain drive.**

Binakan jadual FMEA yang biasa bagi rantai penjana.

(40 marks/*markah*)

[b] **For the chain drive to function, the components should be arranged correctly. Draw a schematic configuration of the components using method of arranging components.**

Agar rantai penjana dapat berfungsi, komponen-komponennya perlu disusun dengan betul. Lukiskan konfigurasi skematik bagi komponen-komponen tersebut dengan menggunakan kaedah menyusun komponen.

(20 marks/*markah*)

[c] **Using the reliability values of components given in Table Q4[c], calculate the reliability for the system.**

Dengan menggunakan nilai kebolehpercayaan bagi komponen di dalam Jadual S4[c], kirakan kebolehpercayaan bagi keseluruhan sistem.

Table Q4[c]: Reliability values of chain components
Jadual S4[c]: Nilai kebolehpercayaan bagi komponen rantai

No.	Components *Komponen*	Component's Reliability *Kebolehpercayaan Komponen*
1.	Roller	0.955
2.	Pin	0.750
3.	Bushing	0.840
4.	Roller Plate	0.999
5.	Pin Plate	0.930

(20 marks/*markah*)

[d] **Calculate the failure rate of chain drive under specific operating condition (failures/million hours) if:**

Base failure rate of chain (failures/million hours) = 15
Multiplying factor for operating service = 1.7
Multiplying factor for chain speed = 1.2
Multiplying factor for chain operating temperature = 1.5
Multiplying factor for lubrication method = 0.8
Multiplying factor for sprocket design = 0.8
Failure rate for driver and driven sprockets (failures/million hours)= 0.8

Kirakan kadar kegagalan bagi rantai penjana pada operasi tertentu (kegagalan/juta jam) jika:

Kadar kegagalan dasar bagi rantai (kegagalan/juta jam) = 15
Faktor darab bagi servis operasi = 1.7
Faktor darab bagi kelajuan rantai = 1.2
Faktor darab bagi suhu operasi rantai = 1.5
Faktor darab bagi kaedah pelinciran = 0.8
Faktor darab bagi rekabentuk sproket = 0.8
Kadar kegagalan bagi pembawa dan sproket yang dibawa (kegagalan/juta jam) = 0.8

(20 marks/*markah*)

Q5. [a] In order to implement ISO 9000,

Draw a flowchart starts from pre-preparation until certification by authorized certification bodies. Furnish the flowchart with relevant Standard Operating Procedures (SOP) on every single step taken.

Bagi pelaksanaan ISO 9000,

Binakan carta aliran bermula daripada pra-persediaan hingga pensijilan dari pihak berkuasa pensijilan. Lengkapkan carta aliran dengan prosedur operasi piawai (SOP) yang sesuai bagi setiap langkah yang diambil.

(40 marks/*markah*)

[b] Develop standard operating procedures (SOP) in developing:

(i) X-bar chart
(ii) S chart
(iii) P- chart

Buatkan prosedur operasi piawai (SOP) dalam menyediakan:

(i) Carta X-bar
(ii) Carta S
(iii) Carta-P

(60 marks/*markah*)

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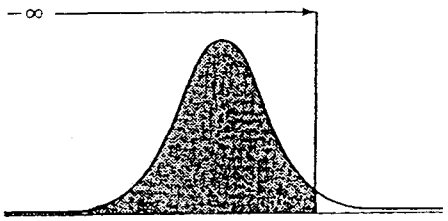
EPM 332 – 2008/2009
Appendix 1



ex: $P(Z \leq 1.96) = 0.9750$

Normal Curve Areas $P(Z \leq Z_0)$

Z	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.00
−3.8	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
−3.7	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
−3.6	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0002	.0002
−3.5	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002
−3.4	.0002	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003
−3.3	.0003	.0004	.0004	.0004	.0004	.0004	.0004	.0005	.0005	.0005
−3.2	.0005	.0005	.0005	.0006	.0006	.0006	.0006	.0006	.0007	.0007
−3.1	.0007	.0007	.0008	.0008	.0008	.0008	.0009	.0009	.0009	.0010
−3.0	.0010	.0010	.0011	.0011	.0011	.0012	.0012	.0013	.0013	.0013
−2.9	.0014	.0014	.0015	.0015	.0016	.0016	.0017	.0018	.0018	.0019
−2.8	.0019	.0020	.0021	.0021	.0022	.0023	.0023	.0024	.0025	.0026
−2.7	.0026	.0027	.0028	.0029	.0030	.0031	.0032	.0033	.0034	.0035
−2.6	.0036	.0037	.0038	.0039	.0040	.0041	.0043	.0044	.0045	.0047
−2.5	.0048	.0049	.0051	.0052	.0054	.0055	.0057	.0059	.0060	.0062
−2.4	.0064	.0066	.0068	.0069	.0071	.0073	.0075	.0078	.0080	.0082
−2.3	.0084	.0087	.0089	.0091	.0094	.0096	.0099	.0102	.0104	.0107
−2.2	.0110	.0113	.0116	.0119	.0122	.0125	.0129	.0132	.0136	.0139
−2.1	.0143	.0146	.0150	.0154	.0158	.0162	.0166	.0170	.0174	.0179
−2.0	.0183	.0188	.0192	.0197	.0202	.0207	.0212	.0217	.0222	.0228
−1.9	.0233	.0239	.0244	.0250	.0256	.0262	.0268	.0274	.0281	.0287
−1.8	.0294	.0301	.0307	.0314	.0322	.0329	.0336	.0344	.0351	.0359
−1.7	.0367	.0375	.0384	.0392	.0401	.0409	.0418	.0427	.0436	.0446
−1.6	.0455	.0465	.0475	.0485	.0495	.0505	.0516	.0526	.0537	.0548
−1.5	.0559	.0571	.0582	.0594	.0606	.0618	.0630	.0643	.0655	.0668
−1.4	.0681	.0694	.0708	.0721	.0735	.0749	.0764	.0778	.0793	.0808
−1.3	.0823	.0838	.0853	.0869	.0885	.0901	.0918	.0934	.0951	.0968
−1.2	.0985	.1003	.1020	.1038	.1056	.1075	.1093	.1112	.1131	.1151
−1.1	.1170	.1190	.1210	.1230	.1251	.1271	.1292	.1314	.1335	.1357
−1.0	.1379	.1401	.1423	.1446	.1469	.1492	.1515	.1539	.1562	.1587
−0.9	.1611	.1635	.1660	.1685	.1711	.1736	.1762	.1788	.1814	.1841
−0.8	.1867	.1894	.1922	.1949	.1977	.2005	.2033	.2061	.2090	.2119
−0.7	.2148	.2177	.2206	.2236	.2266	.2296	.2327	.2358	.2389	.2420
−0.6	.2451	.2483	.2514	.2546	.2578	.2611	.2643	.2676	.2709	.2743
−0.5	.2776	.2810	.2843	.2877	.2912	.2946	.2981	.3015	.3050	.3085
−0.4	.3121	.3156	.3192	.3228	.3264	.3300	.3336	.3372	.3409	.3446
−0.3	.3483	.3520	.3557	.3594	.3632	.3669	.3707	.3745	.3783	.3821
−0.2	.3859	.3897	.3936	.3974	.4013	.4052	.4090	.4129	.4168	.4207
−0.1	.4247	.4286	.4325	.4364	.4404	.4443	.4483	.4522	.4562	.4602
−0.0	.4641	.4681	.4721	.4761	.4801	.4840	.4880	.4920	.4960	.5000

EPM 332 – 2008/2009
Appendix 1 (continued)

Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
+0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
+0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
+0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
+0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
+0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
+0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
+0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
+0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
+0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
+0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
+1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
+1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
+1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
+1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
+1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
+1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
+1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
+1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
+1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
+1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
+2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
+2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
+2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
+2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
+2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
+2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
+2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
+2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
+2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
+2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
+3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
+3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
+3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
+3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
+3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998
+3.5	.9998	.9998	.9998	.9998	.9998	.9998	.9998	.9998	.9998	.9998
+3.6	.9998	.9998	.9999	.9999	.9999	.9999	.9999	.9999	.9999	.9999
+3.7	.9999	.9999	.9999	.9999	.9999	.9999	.9999	.9999	.9999	.9999
+3.8	.9999	.9999	.9999	.9999	.9999	.9999	.9999	.9999	.9999	.9999

Factors for Computing Central Lines and 3σ Control Limits for $\bar{X}$, s, and R Charts

Observations in Sample, n	Chart for Averages: Factors for Control Limits			Chart for Ranges: Factor for Central Line	Chart for Ranges: Factors for Control Limits					Chart for Standard Deviations: Factor for Central Line	Chart for Standard Deviations: Factors for Control Limits			
	A	A_2	A_3	d_2	d_1	D_1	D_2	D_3	D_4	c_4	B_3	B_4	B_5	B_6
2	2.121	1.880	2.659	1.128	0.853	0	3.686	0	3.267	0.7979	0	3.267	0	2.606
3	1.732	1.023	1.954	1.693	0.888	0	4.358	0	2.574	0.8862	0	2.568	0	2.276
4	1.500	0.729	1.628	2.059	0.880	0	4.698	0	2.282	0.9213	0	2.266	0	2.088
5	1.342	0.577	1.427	2.326	0.864	0	4.918	0	2.114	0.9400	0	2.089	0	1.964
6	1.225	0.483	1.287	2.534	0.848	0	5.078	0	2.004	0.9515	0.030	1.970	0.029	1.874
7	1.134	0.419	1.182	2.704	0.833	0.204	5.204	0.076	1.924	0.9594	0.118	1.882	0.113	1.806
8	1.061	0.373	1.099	2.847	0.820	0.388	5.306	0.136	1.864	0.9650	0.185	1.815	0.179	1.751
9	1.000	0.337	1.032	2.970	0.808	0.547	5.393	0.184	1.816	0.9693	0.239	1.761	0.232	1.707
10	0.949	0.308	0.975	3.078	0.797	0.687	5.469	0.223	1.777	0.9727	0.284	1.716	0.276	1.669
11	0.905	0.285	0.927	3.173	0.787	0.811	5.535	0.256	1.744	0.9754	0.321	1.679	0.313	1.637
12	0.866	0.266	0.886	3.258	0.778	0.922	5.594	0.283	1.717	0.9776	0.354	1.646	0.346	1.610
13	0.832	0.249	0.850	3.336	0.770	1.025	5.647	0.307	1.693	0.9794	0.382	1.618	0.374	1.585
14	0.802	0.235	0.817	3.407	0.763	1.118	5.696	0.328	1.672	0.9810	0.406	1.594	0.399	1.563
15	0.775	0.223	0.789	3.472	0.756	1.203	5.741	0.347	1.653	0.9823	0.428	1.572	0.421	1.544
16	0.750	0.212	0.763	3.532	0.750	1.282	5.782	0.363	1.637	0.9835	0.448	1.552	0.440	1.526
17	0.728	0.203	0.739	3.588	0.744	1.356	5.820	0.378	1.622	0.9845	0.466	1.534	0.458	1.511
18	0.707	0.194	0.718	3.640	0.739	1.424	5.856	0.391	1.608	0.9854	0.482	1.518	0.475	1.496
19	0.688	0.187	0.698	3.689	0.734	1.487	5.891	0.403	1.597	0.9862	0.497	1.503	0.490	1.483
20	0.671	0.180	0.680	3.735	0.729	1.549	5.921	0.415	1.585	0.9869	0.510	1.490	0.504	1.470

Percentage Points of the F Distribution (*continued*)

$F_{0.05,\nu_1,\nu_2}$

ν_2 \ ν_1	Degrees of Freedom for the Numerator (ν_1)																		
	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.55	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

Degrees of Freedom for the Denominator (ν_2)