Problem 1. (20 points)

(4 points each) Answer the following multiple-choice questions by circling the letter in the right-hand column that corresponds to the most appropriate response.

A. If a product fails during the "wear-out" portion of the bathtub reliability curve the most likely cause is which of the following? **C**

(a) latent manufacturing defect
(b) random variation
(c) accumulated stress
(d) design error

B. A manufacturing process has an average defect rate of 2.3 defects per unit. Roughly what percentage of units will have exactly three defects? **B**

(a) 10%
(b) 20%
(c) 30%
(d) 40%

Prob {k} = $(dpu^k / k!)\, e^{-dpu}$; Prob {3} = $(2.3^3 / 3!)\, e^{-2.3}$ = 0.203

C. Consider a TEST and REPAIR step in a multi-step manufacturing process. Assuming 100% test coverage, perfect repair, and incoming dpu = 3.25, how many TESTs are required on average to produce 100 good units? **D**

(a) 100
(b) 200
(c) 325
(d) 425

# of Tests = N (dpu + 1) = 100 (3.25 + 1) = 425

D. A manufacturing line produce microprocessors whose average maximum operating clock speed is 750 MHz. Assuming a normal distribution of maximum operating speeds with a standard deviation of 50MHz, approximately what percentage of microprocessors have a maximum operating speeds between 700 and 850 MHz? **B**

(a) 13.59%
(b) 81.86%
(c) 84.14%
(d) 97.73%

700 MHz = 750 – 50 = $-1\,\sigma$; 850 MHz = 750 + 100 = $+2\,\sigma$;
fraction between = 1 – Z(1) – Z(2) = 1 – 0.1587 – 0.0227 = 0.8186

E. What values of Cp and Cpk were required by Motorola's Six Sigma design process to ensure robust design? **C**

(a) $Cp \geq 1.0$, $Cpk \geq 1.0$
(b) $Cp \leq 2.0$, $Cpk \leq 1.5$
(c) $Cp \geq 2.0$, $Cpk \geq 1.5$
(d) $Cp \geq 2.0$, $Cpk \leq 2.0$

Problem 2. (24 points)

(2 points each) In lecture, the design of an RLC filter bank was described as an example of using experiment-based design methods to determine component values and tolerances. For each of the following statements, circle the more appropriate response in the right-hand column to indicate whether or not the statement is an accurate description of experiment-based design.

A. Guaranteed to produce a globally optimal result. **FALSE**

B. Accommodates complex component interactions. **TRUE**

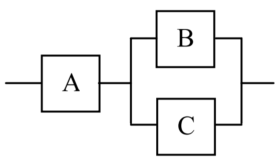
C. Goal is to produce a robust solution that tolerates normal manufacturing variation. **TRUE**

D. Minimizes the number of simulations required. **FALSE**

E. Assumes the system response varies "smoothly" as parameter values change. **TRUE**

For each of the following questions, you must show your work to receive maximum credit.

F. (2 points) A system composed of three sub-systems has a reliability characterized by the series/parallel structure pictured below. Write an equation for the system reliability as a function of the individual sub-system reliabilities, R_A, R_B, and R_C.



$$\mathbf{R_{SYSTEM} = R_A\,(R_B \parallel R_C)}$$
$$\mathbf{= R_A\,[\,1 - (1 - R_B)\,(1 - R_C)\,]}$$

G. (4 points) A device is composed of two elements (J and K) with parallel reliabilities characterized by constant per unit failure rates of $\lambda_J = 1\text{x}10^{-4}$/hr and $\lambda_K = 5\text{x}10^{-3}$/hr. Assuming there are initially 5,000 devices, how many survive past 100 hours of their life?

$$\mathbf{R_J(100) = e^{-.0001\,(100)} = e^{-.01} = 0.990}$$

$$\mathbf{R_K(100) = e^{-.005\,(100)} = e^{-.5} = 0.607}$$

$$\mathbf{(R_J \parallel R_K) = (1 - R_B)\,(1 - R_C) = 0.996}$$

$$\mathbf{N_S(t) = N_0\,R(t) = 5000\,(0.996) = 4980}$$

H. (8 points) 1,000 systems are being operated for 500 hours. Each system consists of two serial sub-systems with reliabilities of 0.8 and 0.9 at 300 hours. How many of these systems have failed by 300 hours of operation? Assuming the sub-systems are characterized by constant per unit failure rates, how many of these systems are still operating at 500 hours?

$$\mathbf{R_{SYS} = R_A\,R_B = e^{-\lambda A\,t}\,e^{-\lambda B\,t} = e^{-(\lambda A + \lambda B)\,t} = e^{-\lambda SYS\,t}}$$

$$\mathbf{N_S(300) = N_0\,R_{SYS}(300) = 1000\,(0.8)(0.9) = 720 \Rightarrow N_F(300) = N_0 - N_S(300) = 1000 - 720 = 280}$$

$$\mathbf{R_{SYS}(300) = e^{-\lambda SYS\,(300)}\,;\ 0.72 = e^{-\lambda SYS\,(300)}\,;\ \ln(0.72) = \ln(e^{-\lambda SYS\,(300)}) = -300\,\lambda_{SYS}}$$

$$\mathbf{\lambda_{SYS} = 0.001095}$$

$$\mathbf{R_{SYS}(500) = e^{-\lambda SYS\,(500)} = 0.5784 \Rightarrow N_S(500) = 1000\,(0.578) = 578}$$

Problem 3. (16 points)

A. (6 points) Determine the critical path and its duration for the following CPM chart. State the path in terms of activity letters in order from start to finish. (example: path=AFJO, duration=9)

Critical Path = **C E D F I M Q** Duration = **15**

B. (6 points) Referring to the above CPM chart, determine the float for each of the activities listed below. Show your work.

(i) Activity F

F is on critical path, therefore Float(F) = 0

Float F = **0**

(ii) Activity G

Latest start (G) = Duration – GMQ = 15 – 7 = 8
Earliest start (G) = CE = 4
Float(G) = latest start – earliest start = 8 – 4

Float G = **4**

C. (4 points) Assume that for a slightly different diagram, a PERT chart, the project duration is 18 months and the variance is 16 months^2. Determine the probability that the project will require greater than 12 months to complete.

Variance = StDev^2 => $\sigma = \sqrt{16} = 4$ mo
12 mo = 18 mo – 6 mo => –1.5 σ
Prob { >12 mo} = 1 – Z(1.5) = 1 – 0.0668 = 0.9332

Probability = **93.32%**

Problem 5. (16 points)

A. (2 points) List two characteristics generally associated with a profession as opposed to other types of jobs.

Possible answers include self-regulation, peer review and discipline, requires skills and judgment that is not routine or mechanized, requires extensive formal training or education, commitment to serve the public good, professional organization to set standards and codes of practice, and licensure.

B. (2 points) What is generally stated as the primary justification for government regulation and licensure of engineers and other professionals?

Protection of public health, safety, and welfare.

C. (2 points) List two methods by which societies like IEEE support the practice of engineering as a profession.

Possible answers include providing continuing education and training, setting standards, defining educational requirements and accreditation, peer review, and publication on research and practices.

D. (10 points) **Many possible answers.**

Problem 4. (24 points)

A. (16 points) Complete the following table. Assume design specifications are symmetric around the target mean and that the characteristics of the manufactured item are distributed according to a normal (Gaussian) distribution. You must show your calculations in the space below (or on the back of *this* page) in order to receive full credit.

Lower Spec Limit	**Target Mean**	**Upper Spec Limit**	**Actual Mean**	**Standard Deviation**	**Cp**	**Cpk**	**Defective (Below LSL)**	**Defective (Above USL)**
520	550	**580**	560	12	**0.833**	0.5556	**Z(3.33) ≈ 0.043 %**	**Z(1.67) ≈ 4.746 %**
–6.6 σ	0 σ	**6.6 σ**	**–0.4 σ**	σ	**2.2**	**2.067**	Z(6.2) ≈ 2.8×10^{-8} %	Z(7.0) ≈ 1.3×10^{-10} %

Cp = (USL – LSL) / 6 σ   Cpk = Cp (1 – k)   k = |AM – TM| / ((USL – LSL) / 2)

Row 1:

Cpk = Cp { 1 – [|AM – TM| / ((USL – LSL) / 2)] } = Cp { 1 – [|560 – 550| / ((6 σ Cp) / 2)] }

Cpk = Cp – [Cp (10) / (3 σ Cp)] = Cp – [10 / 36] => Cp = Cpk + 10/36 = 0.833

(USL – LSL) = 6 σ Cp = 6 (12) (0.833) = 60 => LSL = TM – 60/2; USL = TM + 60/2

Defects below: 520 = 560 – 40 = 560 – 3.33 σ; Defects above: 580 = 560 + 20 = 560 + 1.67 σ

Row 2:

Z(6.2) => AM – LSL = 6.2 σ; Z(7.0) => USL – AM = 7.0 σ; USL – LSL = 6.2 σ + 7.0 σ = 13.2 σ

LSL = TM – 13.2 σ /2 = –6.6 σ; USL = TM + 13.2 σ /2 = 6.6 σ

AM = LSL + 6.2 σ = –0.4 σ

Cp = (USL – LSL) / 6 σ = 13.2 σ / 6 σ = 2.2

Cpk = Cp { 1 – [|AM – TM| / ((USL – LSL) / 2)] } = 2.2 { 1 – [|–0.4 σ – 0 σ | / (13.2 σ / 2)] }

= 2.2 { 1 – [0.4σ / 6.6σ] } = 2.2 (1 – 0.0606) = 2.067

B. (8 points) Using the axes provided below, sketch these situations. Include (and label) the target mean, upper and lower specification limits, the actual mean, the standard deviation, and the probability distribution curve.

Sketches corresponding to above situations, with values shown in the table.