STUDY PROBLEMS #2 -- SOLUTIONS

1. Since all three components must work for the bus to work, $R_{bus} = R_1 R_2 R_3$; $R_i = e^{-\lambda i t}$; $\lambda i = 1/MTBFi$

   $Rbus = e^{-(1/MTBF1 + 1/MTBF2 + 1/MTBF3)t} = e^{-(1/600000 + 1/740000 + 1/610000)\,500000} = 0.102$

   Prob (failure) = 1 – Reliability = 89.8%

2. For a series connection, R = R1 R2; for a parallel connection, R = 1 – (1 – R1)(1 – R2)

   There are 6 possible configurations, depending on how the diagrams are labeled. By trying all possibilities, in can be determined that the most reliable configuration is configuration 1, with A and C in parallel.

   $R_{AC} = (0.95)(0.90) = 0.855$; $R_{ABC} = 1 - (1 - R_{AC})(1 - R_B) = 1 - (1 - 0.855)(1 - 0.99) = 0.9986$

3. Key equations: Cp = (USL – LSL) / 6 σ
   Cpk = Cp (1 – k), k = |Actual mean – Target mean| / [0.5 (USL – LSL)]

Lower Spec Limit	Target Mean	Upper Spec Limit	Actual Mean	Standard Deviation	Cp	Cpk	Percent Defective	Percent Good
450	500	550	505	15	1.11	1.0	Z(3.0) + Z(3.67) = 0.15%	99.85%
2000	2600	3200	2500 or 2700	100	2.0	1.67	Z(5.0) + Z(7.0) ≅ 0	≅ 100%
910	1000	1090	975	20	1.5	1.08	Z(5.75) + Z(3.25) = 0.06%	99.94%
–4 σ	0 σ	+4 σ	–0.5 σ	σ	1.33	1.17	Z(4.5) + Z(3.5) = 0.02%	99.98%
–5.4 σ	0 σ	+5.4 σ	±1.8 σ	σ	1.8	1.2	Z(3.6) + Z(7.2) = 0.02%	99.98%

4. A product with built-in obsolescence may be appropriate if there is some offsetting benefit. For example, light bulbs, disposable syringes, and styrofoam cups offer convenience and/or greater safety. In all of these cases, alternative products are available, so the built-in obsolescence is not denying consumers access to "better" products or forcing them to accept higher costs.

5. Lots of possible answers. Utilitarianism is probably the most commonly used, but duty-based and rights-based can also be readily applied to engineering.

Problem 2. (12 points)

A. (4 points) The tail-end Z function corresponds to the probability that a value randomly selected from a normally-distributed population will be greater than (to the right of) a specified value; i.e, Z(x1) = Pr (x > x1), where x and x1 are expressed in units of standard deviation.

Since the Tail-End Z-Table distributed in class only includes positive values, it cannot be used directly to look up Z(x1) if x1 < 0. Write an expression for Z(x1), for x1 < 0, that can be evaluated using that table.

$Z(x1)_{x1<0} = 1 - Z(-x1)$

Write an expression, in terms of the tail-end Z function, for determining the probability that a randomly selected value will fall between two values, x1 and x2, x1 ≤ x2. Then, compute this function for the two sets of x1 and x2 values given. Write your answers in the boxes at the right margin.

Pr (x1 ≤ x ≤ x2) = Z (x1) – Z (x2)

x1 = 1.07 σ; x2 = 2.72 σ — Z(1.07) – Z(2.72) = .1423 – .00326 — **.1390**

x1 = (-2.13 σ); x2 = 0.69 σ — Z(-2.13) – Z(0.69) = 1 – Z(2.13) – Z(0.69) = 1 – .0166 – .2451 — **.7383**

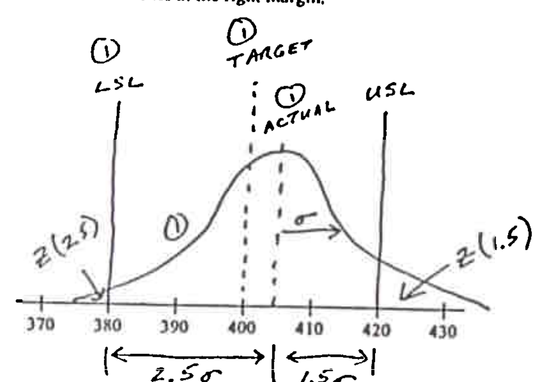
B. (8 points) A product design has the following specification for a particular parameter:

Target value: 400 Tolerance: ± 5%

When actually manufactured, this parameter varies according to a normal distribution. The following results are measured for this particular parameter:

Actual mean: 405 Standard Deviation: 10

Using the axis provided, sketch this situation in the space below. Include (and label) the target value, upper and lower specification limits, the actual mean, and the probability distribution curve. Compute the following values: percent of manufactured product below specification, percent of manufactured product above specification, the process capability index Cp, and the shifted process capability index Cpk. Write your answers in the boxes at the right margin.



% below	0.621 %	Z(2.5)
% above	6.68 %	Z(1.5)
Cp	0.667	
Cpk	0.500	Cpk = Cp(0.75)

$C_p = \frac{USL - LSL}{6\sigma} = \frac{420 - 380}{6 \cdot 10} = \frac{40}{60}$

$C_{pk} = C_p(1-k)$, $k = \frac{|TARGET - ACTUAL|}{\frac{1}{2}(USL - LSL)}$

k = [illegible] = 0.25

Name: SOLUTION   Student #:

Problem 1. (14 points)

For each of the following questions, circle the letter in the right-hand column that corresponds to the best answer.

A. Using the Tail-End Z-function, Z(x), the fraction of the normal distribution between $-1.5\,\sigma$ and $+3.0\,\sigma$ is given by which of the following computations? — a b c (d)

(a) Z(3.0) – Z(1.5)
(b) Z(3.0) + Z(–1.5)
(c) Z(1.5) – Z(3.0)
(d) Z(–1.5) – Z(3.0)

B. The percentage of the normal distribution within ±1.2 standard deviations of the mean is most closely equal to which of the following values? — a b (c) d

Z(1.2) = 11.5%

(a) 11.5 %
(b) 23.0 %
(c) 77.0 %
(d) 89.5 %

C. The design specification for a part characteristic is 600 ± 40. The manufacturing process has an actual mean of 615 and a standard deviation of 10. The fraction of parts that are defective (out of spec) is given by which of the following computations? — (a) b c d

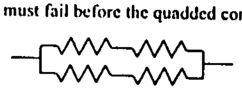
5σ 615 2.5σ; 560 640

(a) Z(2.5) + Z(5.5)
(b) 1 – Z(2.5) – Z(5.5)
(c) Z(4.0) + Z(4.0)
(d) (1 – Z(2.5)) + (1 – Z(5.5))

D. The reliability of a system can be increased by adding a redundant element in parallel, provided only one functioning element is required for the system to function correctly and the reliability of the added element is _______ the reliability of the original element. — a b c (d)

(a) less than
(b) equal to
(c) greater than
(d) all of the above

E. To improve reliability, a single resistor (of value R) is replaced by the "quadded component" shown (each resistor has the value R). Assuming resistors may fail as either an open-circuit or as a short-circuit, what is the minimum number of resistors that must fail before the quadded component stops functioning as a resistor? — a (b) c d



(a) 1
(b) 2
(c) 3
(d) 4

F. Which of the following is not a possible equivalent resistance for the quadded component from question E, after it "partially fails" but still functions as a resistor? — a b (c) d

(a) R / 2   R ‖ R
(b) 2R / 3   (R+R) ‖ R
(c) 3R / 2
(d) 2R   (R+R) ‖ open

G. Which of the following steps is not required to become a registered (licensed) professional engineer? — (a) b c d

(a) complete a master's degree
(b) work as an engineer
(c) pass the Fundamentals of Engineering exam
(d) pass the Principles and Practices exam

Name: SOLUTION   Student #:

Problem 2. (16 points)

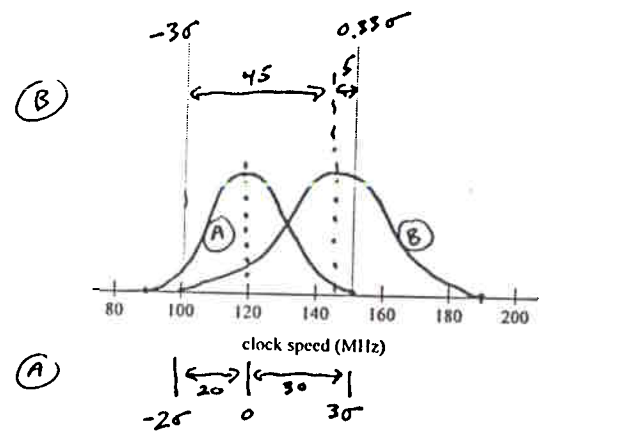
Just as manufacturers may use "binning" to select components close to a desired value, "speed grading" may be used to identify microprocessors that will work correctly at faster speeds, so that they can be sold for a higher price. Assume a manufacturer wishes to sell a particular microprocessor, with two possible speeds: 100 MHz and 150 MHz. Each chip is first tested at 150 MHz; those that fail are then tested again at 100 MHz. Chips that fail the second test are discarded, while the others are labeled based on the speed at which they passed the test.

While the manufacturing process is intended to produce devices that work at a particular clock speed, assume that the highest speed at which a specific chip will function is normally distributed. A and B, below, describe the distribution of maximum clock speeds for two possible manufacturing processes.

A. Actual mean: 120 MHz   Standard Deviation: 10 MHz

B. Actual mean: 145 MHz   Standard Deviation: 15 MHz

Using the axis provided below, sketch both distributions (label the curves "A" and "B"). For each option, compute the following values: percent sold as 150 MHz, percent sold as 100 MHz, and percent discarded. Write your answers in the boxes at the right margin. *Show your work*; if you need more space, use the back of this page.



Process A:

150 MHz	0.135 %
100 MHz	97.59 %
Discarded	2.275 %

Process B:

150 MHz	37.07 %
100 MHz	62.795 %
Discarded	0.135 %

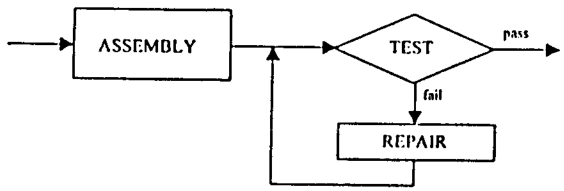
(A)
150 : Z (3.0) = 0.135 %
DIS : Z (2.0) = 2.275 %
100 : 100 – 0.135 – 2.275 = 97.59

(B)
150 : Z (0.33) = 37.07 %
DIS : Z (3.00) = 0.135 %
100 : 100 – 37.07 – 0.135 = 62.795

Name: SOLUTION Student #:

Problem 2. (12 points)

A portion of a multi-step manufacturing process is illustrated below. Operating costs (parts, electricity, labor, etc.) for the assembly step total $237.28 per unit assembled. Upon completion of the assembly step, each unit has an average of 1.4 defects. The cost of each test is $15.00 and the cost of repair averages $42.00 per unit repaired. Assume that the repair process is perfect and that the test coverage is perfect (c = 1).



Answer each of the following questions regarding this process. Place your final answers in the boxes at the right edge. You must show equations and/or calculations to justify your answers in order to receive full credit.

A. (2 points) The equipment used in the assembly step costs $65,000 and has an expected useful lifetime of 10 years and no salvage value. Assuming an interest rate of 7%, what is the annualized cost of this equipment? **9254.54**

$65000\,(A/P,\,7\%,\,10) = 65000\left[\frac{.07(1.07)^{10}}{(1.07)^{10}-1}\right] = 65000\,(.1424)$

B. (2 points) What percentage of units are defect-free after the assembly step? **24.66 %**

$FTY = e^{-d_{pu}} = e^{-1.4} = .2466$

C. (3 points) Assuming a total of 1000 units are built each year, what is the average cost of producing one unit? **377.34**

$\frac{9254.54}{1000} + 273.28 + (1.4+1)(15.00) + (1.4)(42)$

$= 9.26 + 273.28 + 36.00 + 58.80 = 377.34$

A new engineer suggests that your company is spending too much on testing and repairing defective units. She suggests that defective units be scrapped, instead. Assume the salvage value of a scrapped unit is $92.00 and that the existing assembly equipment has sufficient capacity to build the additional units.

D. (2 points) How many units will need to be assembled (on average) in order to yield one defect-free unit? **4.06**

$1/FTY = e^{d_{pu}} = e^{1.4} = 4.06$

E. (3 points) Assuming a total of 1000 defect-free units are built each year, what is the average cost of producing one defect-free unit? **752.00**

$\frac{9254.54}{1000} + 4.06\,(237.28 + 15.00) - 3.06\,(92.00)$

$= 9.26 + 1024.26 - 281.52 = 752.00$

Name: SOLUTION Student #:

Problem 3. (16 points)

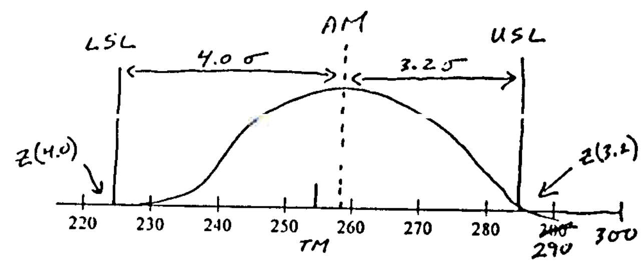
A. (10 points) Complete the following table. Assume design specifications are symmetric around the target mean and that the characteristics of the manufactured item are distributed according to a normal (Gaussian) distribution. You must show your calculations in the space below (or on the back of *this* 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)
224.4	255	285.6	258.4	8.5	1.2	1.07	Z(4.0) = 0.0032%	Z(3.2) = 0.0687%
-2.7σ	0σ	2.7σ	-0.17σ	σ	0.9	.843	Z(2.53) = 0.57%	Z(2.87) = 0.21%

B. (6 points) Using the axes provided, sketch these situations in the spaces below. Include (and label) the target value, upper and lower specification limits, the actual mean, and the probability distribution curve.

$TM = (224.4 + 285.6)/2 = 255$

$\sigma = \frac{285.6 - 224.4}{3.2 + 4.0} = 8.5$



$4\sigma = 4(8.5) = 34$

$224.4 + 34 = 258.4 = AM$

$C_p = \frac{USL - LSL}{6\sigma} = 1.2$

$k = \frac{|AM - TM|}{\frac{1}{2}(USL - LSL)} = \frac{3.4}{30.6} = .111$

$C_{pk} = C_p(1-k) = 1.07$

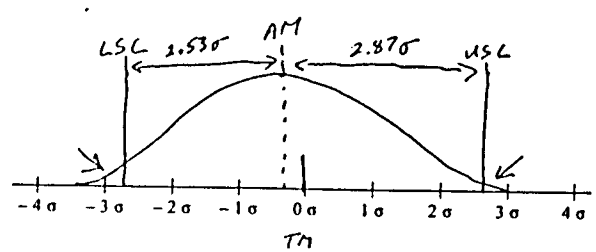
$C_p = 0.9 = \frac{USL - LSL}{6\sigma}$

$USL - LSL = 5.4\sigma$

$5.4\sigma/2 = 2.7\sigma$

$k = \frac{|AM - TM|}{\frac{1}{2}(USL - LSL)} = \frac{0.17}{2.7} = .063$

$C_{pk} = 0.9(1-k) = .843$



Name: SOLUTION Student #:

Problem 3. (12 points)

Answer each of the following questions by circling either TRUE or FALSE in the left-hand column.

TRUE	(FALSE)	The primary purpose of accelerated stress testing is to reduce the failure rate during the "useful lifetime" of a product.
(TRUE)	FALSE	Under normal economic circumstances, the present value of a future transaction decreases as the time interval increases.
(TRUE)	FALSE	The "utilitarian" model of morality emphasizes maximizing the benefit of a decision; i.e., "the most good for the most people".
TRUE	(FALSE)	One of the major advantages of experiment-based design methods is that they produce globally-optimal solutions.
(TRUE)	FALSE	Engineering licensure was instituted by states to protect the life, health, and property of the general public.
(TRUE)	FALSE	The use of sampling techniques to characterize a product or process is more accurate for parameters that have a small standard deviation.
TRUE	(FALSE)	Most engineering disasters have a single, identifiable cause and could have been avoided by better design.
(TRUE)	FALSE	Given a geometric gradient series of payments over n years, there is always a uniform series of payments over n years that has the same present value.
(TRUE)	FALSE	One of the major causes of failures during the "infant mortality" period is latent defects that were not detected during the manufacturing process.
TRUE	(FALSE)	The "rights-based" model of morality is based on your right to act in your own best interest.
(TRUE)	FALSE	One of the major advantages of experiment-based design methods is that they can produce designs that are tolerant of normal manufacturing variation.
(TRUE)	FALSE	Given the tail-end Z-function, Z(x), the cumulative distribution function can be computed as follows: CDF(x) = Z(−x).