

## SOLUTIONS TO PROBLEMS IN CHAPTER 2

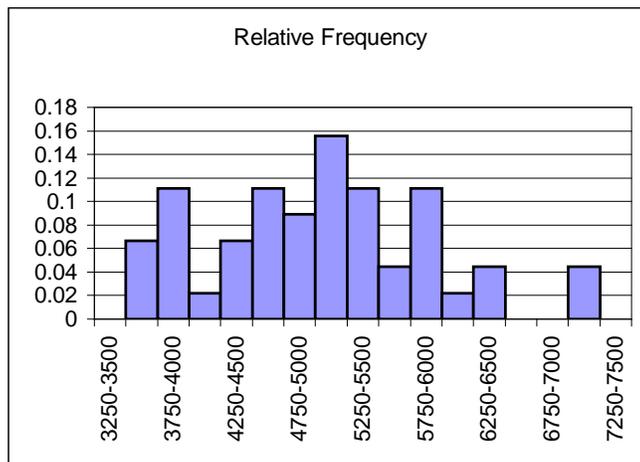
Problem 2.1. The results of tests to determine the modulus of rupture (MOR) for a set of timber beams are shown in Table P2.1.

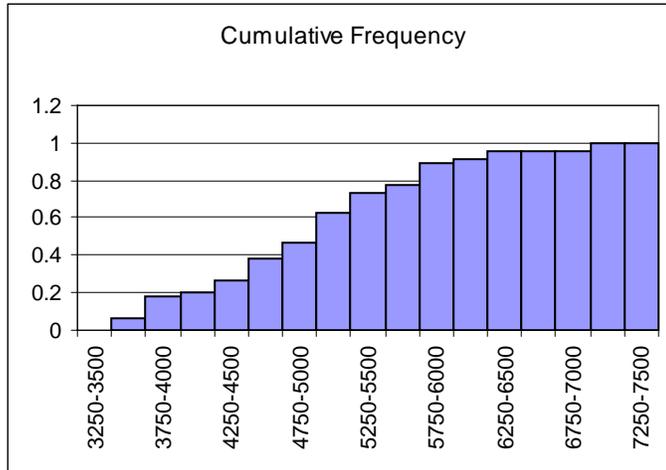
- A. Plot the relative frequency and cumulative frequency histograms.
- B. Calculate the sample mean, standard deviation, and coefficient of variation.
- C. Plot the data on normal probability paper.

*Solution:*

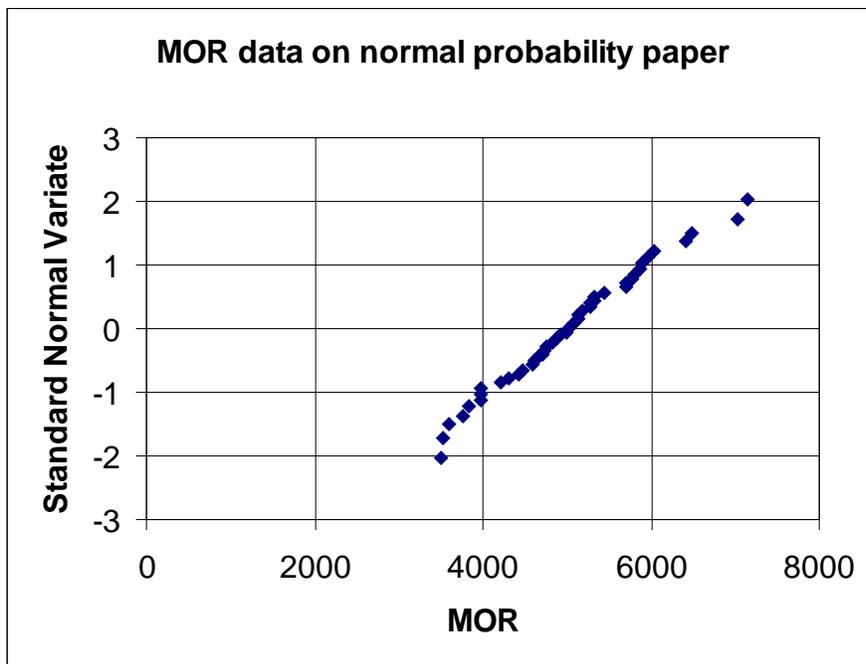
- A. For the histogram plots, the interval size is chosen to be 250. There are 45 data points.

Interval	Relative Frequency	Cumulative Frequency
3250-3500	0	0
3500-3750	0.06667	0.066667
3750-4000	0.11111	0.177778
4000-4250	0.02222	0.200000
4250-4500	0.06667	0.266667
4500-4750	0.11111	0.377778
4750-5000	0.08889	0.466667
5000-5250	0.15556	0.622222
5250-5500	0.11111	0.733333
5500-5750	0.04444	0.777778
5750-6000	0.11111	0.888889
6000-6250	0.02222	0.911111
6250-6500	0.04444	0.955556
6500-6750	0	0.955556
6750-7000	0	0.955556
7000-7250	0.04444	1
7250-7500	0	1





- B. Using Eqns. 2.25 and 2.26, sample mean =  $\bar{x} = 5031$  and sample standard deviation =  $s_x = 880.4$ . The coefficient of variation based on sample parameters is  $s_x / \bar{x} = 0.175$ .
- C. The step-by-step procedure described in Section 2.5 is followed to construct the plot on normal probability paper.



**Problem 2.2.** A set of test data for the load-carrying capacity of a member is shown in Table P2.2.

- Plot the test data on normal probability paper.
- Plot a normal distribution on the same probability paper. Use the sample mean and standard deviation as estimates of the true mean and standard deviation.
- Plot a lognormal distribution on the same normal probability paper. Use the sample mean and standard deviation as estimates of the true mean and standard deviation.

D. Plot the relative frequency and cumulative frequency histograms.

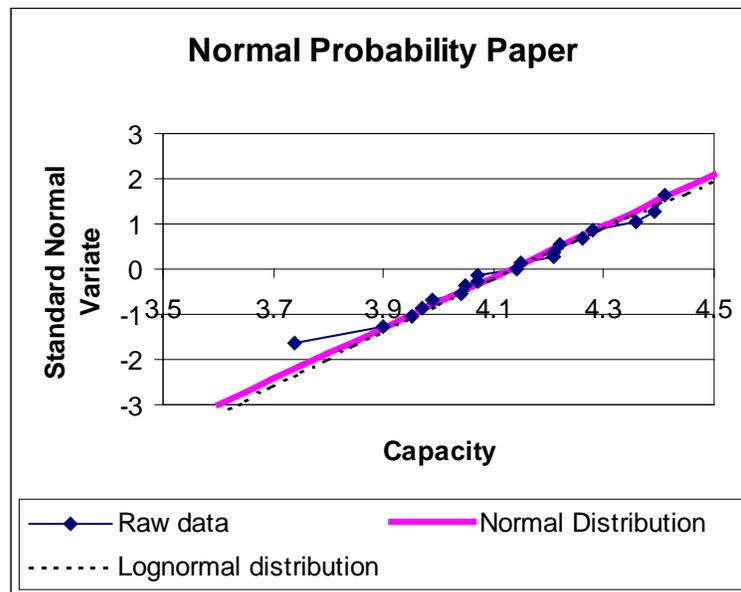
*Solution:*

A. Using Eqns. 2.25 and 2.26, the sample mean, sample standard deviation, and sample coefficient of variation are

$$\bar{x} = 4.127 \quad s_x = 0.1770 \quad \text{CoV} = s_x / \bar{x} = 0.04289$$

To plot on normal probability paper, we follow the step-by-step procedure outlined in Section 2.5.

Raw Data	Sorted	i	$i/(N+1)=p_i$	$\Phi^{-1}(p_i)$
3.95	3.74	1	0.05	-1.64485
4.07	3.90	2	0.10	-1.28155
4.14	3.95	3	0.15	-1.03643
3.99	3.97	4	0.20	-0.84162
4.21	3.99	5	0.25	-0.67449
4.39	4.04	6	0.30	-0.5244
4.21	4.05	7	0.35	-0.38532
3.90	4.07	8	0.40	-0.25335
3.74	4.07	9	0.45	-0.12566
4.28	4.14	10	0.50	0
4.15	4.15	11	0.55	0.125661
4.04	4.21	12	0.60	0.253347
4.26	4.21	13	0.65	0.385321
4.41	4.22	14	0.70	0.524401
4.22	4.26	15	0.75	0.67449
4.07	4.28	16	0.80	0.841621
3.97	4.36	17	0.85	1.036433
4.05	4.39	18	0.90	1.281551
4.36	4.41	19	0.95	1.644853



- B. See part A. To plot the normal distribution on normal probability paper: (1) Calculate values of the standard normal variable  $z$  for some arbitrary values of  $x$  (in ascending order) in the range of interest. The formula for  $z$  is

$$z = \frac{x - \mu_X}{\sigma_X} = \frac{x - 4.127}{0.1770}$$

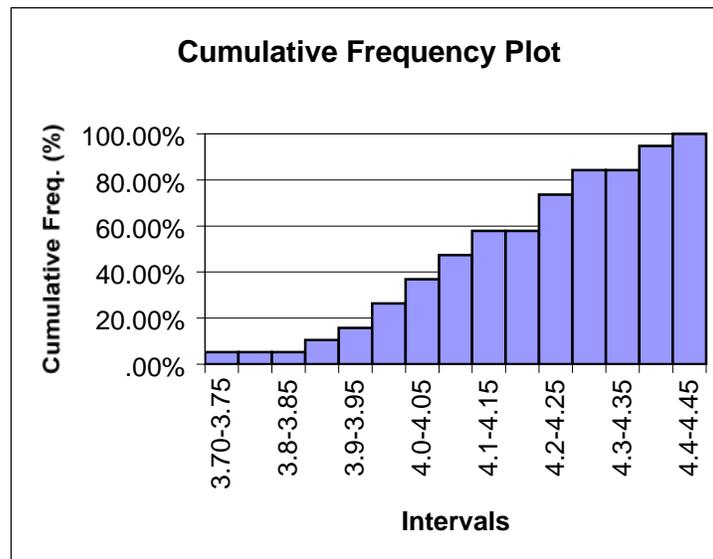
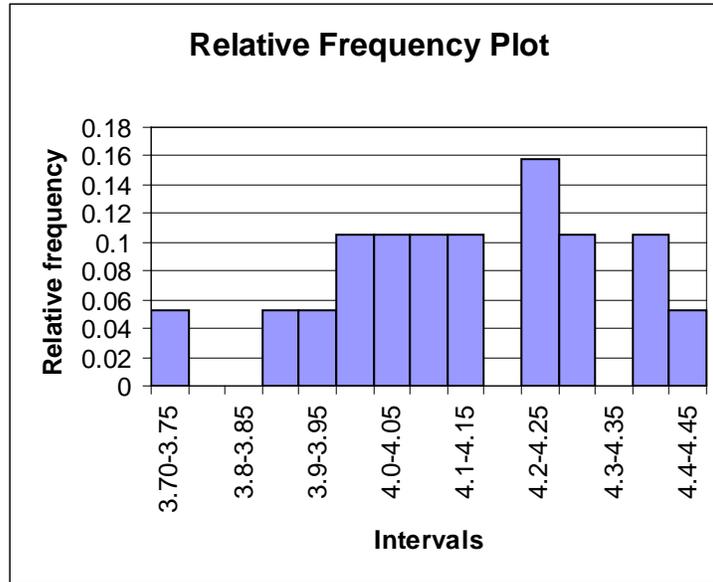
- (2) Plot  $z$  versus  $x$  on standard linear graph paper. The plot is shown in the graph in Part A. Note that the relationship between  $z$  and  $x$  is linear, so only two points are needed to plot the graph.
- C. To plot a lognormal distribution, we need the lognormal distribution parameters. We will assume that  $\mu_X = \bar{x}$  and  $\sigma_X = s_X$ .

$$\sigma_{\ln X}^2 = \ln(1 + V_X^2) = \ln(1 + (0.04289)^2) \Rightarrow \sigma_{\ln X} = 0.04287$$

$$\mu_{\ln X} = \ln(\mu_X) - 0.5\sigma_{\ln X}^2 = \ln(4.127) - 0.5(0.04287)^2 = 1.417$$

- To plot the lognormal distribution on normal probability paper: (1) Calculate  $F_X(x)$  for some arbitrary values of  $x$  (in ascending order) in the range of interest.  $F_X(x)$  is the lognormal distribution, and it can be calculated as shown in Section 2.4.3. (2) Use the values of  $F_X(x_i)$  as the values of  $p_i$  for plotting points on normal probability paper. (3) Calculate  $z_i = \Phi^{-1}(p_i)$ . (4) Plot  $z_i$  versus  $x_i$ . The plot is shown in the graph in Part A.
- D. There are 19 data points. The interval size was chosen to be 0.05.

Interval	Number	Cumulative %
3.70-3.75	1	5.26%
3.75-3.8	0	5.26%
3.8-3.85	0	5.26%
3.85-3.9	1	10.53%
3.9-3.95	1	15.79%
3.95-4.0	2	26.32%
4.0-4.05	2	36.84%
4.05-4.1	2	47.37%
4.1-4.15	2	57.89%
4.15-4.2	0	57.89%
4.2-4.25	3	73.68%
4.25-4.3	2	84.21%
4.3-4.35	0	84.21%
4.35-4.4	2	94.74%
4.4-4.45	1	100.00%



**Problem 2.3.** For the data in Table 2.5, calculate the statistical estimate of the correlation coefficient using Equation (2.99).

*Solution:*

The formula is

$$\hat{\rho}_{XY} = \frac{1}{n-1} \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{s_X s_Y} = \frac{1}{n-1} \frac{\left( \sum_{i=1}^n x_i y_i \right) - n\bar{x}\bar{y}}{s_X s_Y}$$

Note that it doesn't matter which variable is x and which is y. There are 100 data points. After manipulating the data, you should find:

$$\begin{aligned} \text{for } f'_c \quad & \bar{x} = 2743.82 \quad s_x = 520.082 \\ \text{for } E \quad & \bar{y} = 2991380 \quad s_y = 361245 \\ & \hat{\rho}_{XY} = 0.806 \end{aligned}$$

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**Problem 2.4.** A variable X is to be modelled using a uniform distribution. The lower bound value is 5, and the upper bound value is 36.

- A. Calculate the mean and standard deviation of X.
- B. What is the probability that the value of X is between 10 and 20?
- C. What is the probability that the value of X is greater than 31?
- D. Plot the CDF on normal probability paper.

*Solution:*

- A. The value of a is 5, and the value of b is 36. (Refer to Eqn. 2.31.) Using Eqns. 2.32 and 2.33,

$$\begin{aligned} \mu_x &= \frac{a+b}{2} = 20.5 \\ \sigma_x^2 &= \frac{(b-a)^2}{12} = 80.1 \Rightarrow \sigma_x = 8.95 \end{aligned}$$

- B. Using Eqn. 2.31 and the definition of CDF (Eqn. 2.13),

$$F_X(x) = \int_5^x \frac{1}{b-a} d\xi = \frac{1}{31}(x-5)$$

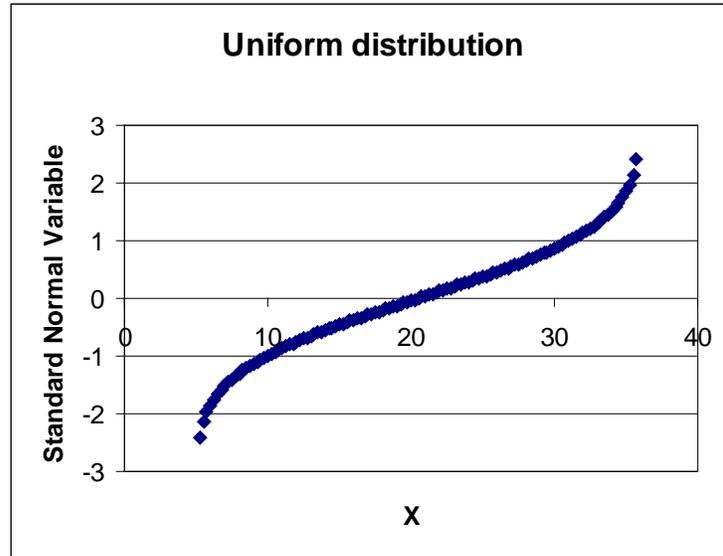
Therefore, using Eqn. 2.15

$$P(10 \leq x \leq 20) = F_X(20) - F_X(10) = \frac{15}{31} - \frac{5}{31} = 0.3226$$

- C.

$$P(X > 31) = 1 - P(X \leq 31) = 1 - F_X(31) = 1 - \frac{26}{31} = 0.1613$$

- D. To plot the uniform distribution on normal probability paper: (1) Calculate  $F_X(x)$  for some arbitrary values of x (in ascending order) in the range of interest.  $F_X(x)$  is the uniform distribution, and its range is limited. (2) Use the values of  $F_X(x_i)$  as the values of  $p_i$  for plotting points on normal probability paper. (3) Calculate  $z_i = \Phi^{-1}(p_i)$ . (4) Plot  $z_i$  versus  $x_i$  on standard linear graph paper as shown below.

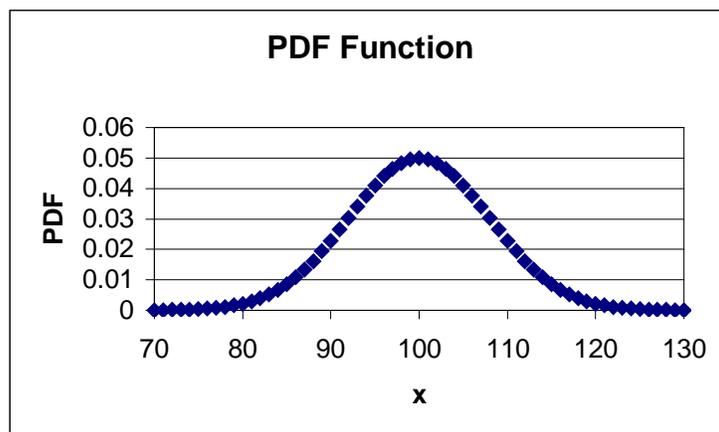


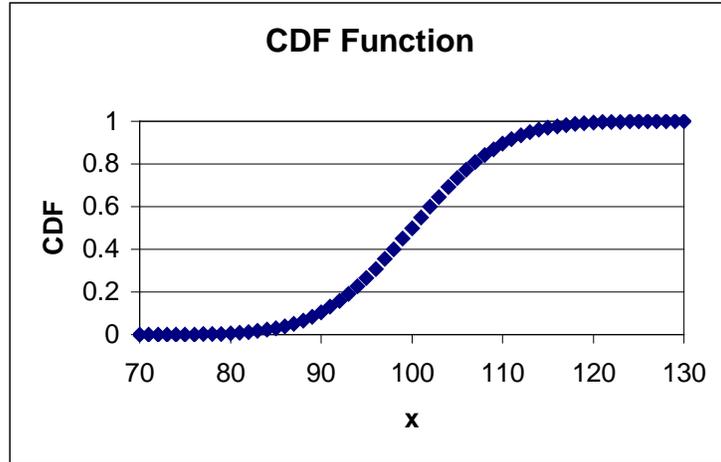
**Problem 2.5.** The dead load  $D$  on a structure is to be modelled as a normal random variable with a mean value of 100 and a coefficient of variation of 8%.

- A. Plot the PDF and CDF on standard graph paper.
- B. Plot the CDF on normal probability paper.
- C. Determine the probability that  $D$  is less than or equal to 95.
- D. Determine the probability that  $D$  is between 95 and 105.

*Solution:*

- A. The formulas for PDF and CDF are given by Eqns. 2.34 and 2.39. The value of  $\sigma_D$  is  $V_D \mu_D = 0.08(100)=8$ . Appendix B can be used to determine values of CDF, or a computer spreadsheet program can be used.

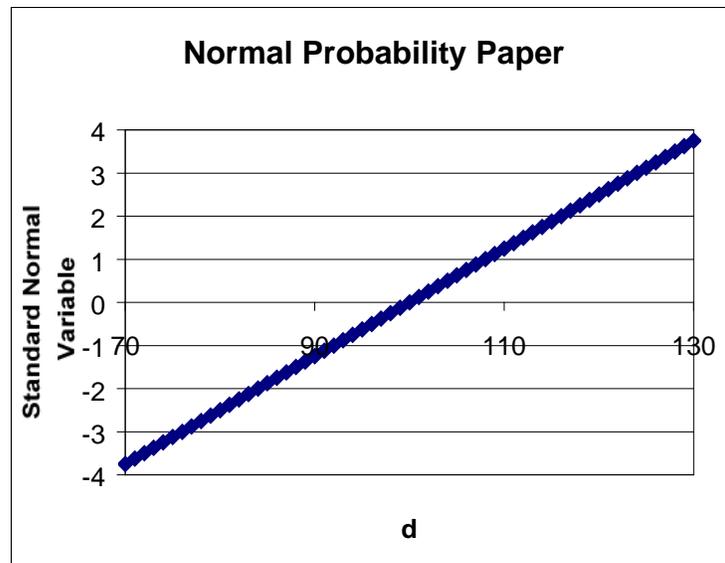




B. To plot the normal distribution on normal probability paper: (1) Calculate values of the standard normal variable  $z$  for some arbitrary values of  $d$  (in ascending order) in the range of interest. The formula for  $z$  is

$$z = \frac{d - \mu_D}{\sigma_D} = \frac{d - 100}{8}$$

(2) Plot  $z$  versus  $d$  on standard linear graph paper. Note that the relationship between  $z$  and  $d$  is linear, so only two points are needed to plot the graph.



C.

$$P(D \leq 95) = \Phi\left(\frac{95 - 100}{8}\right) = \Phi(-0.625) = 0.266$$

D.

$$P(95 \leq D \leq 105) = \Phi\left(\frac{105-100}{8}\right) - \Phi\left(\frac{95-100}{8}\right) = \Phi(0.625) - \Phi(-0.625) = 0.468$$

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**Problem 2.6.** The ground snow load  $q$  (in pounds per square foot) is to be modelled as a lognormal random variable. The mean value of the ground snow load is 8.85 psf, and the standard deviation is 5.83 psf.

- A. Plot the PDF and CDF on standard graph paper.
- B. Plot the CDF on normal probability paper.
- C. Determine the probability that  $q$  is less than or equal to 7.39 psf.
- D. Determine the probability that  $q$  is between 6 and 8 psf.

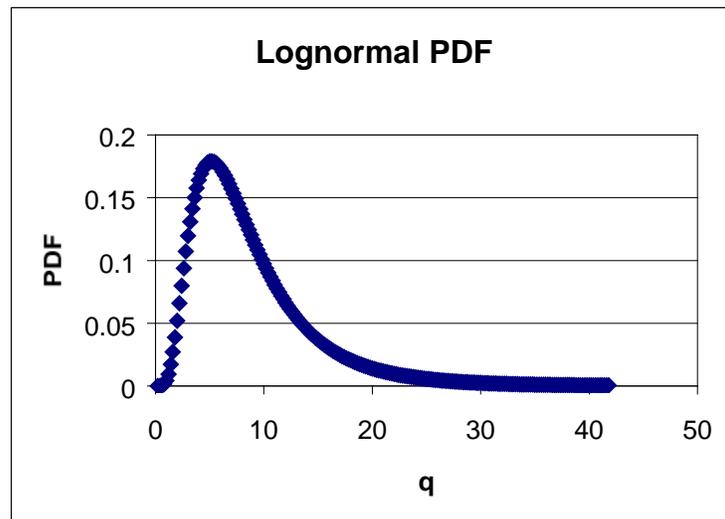
*Solution:*

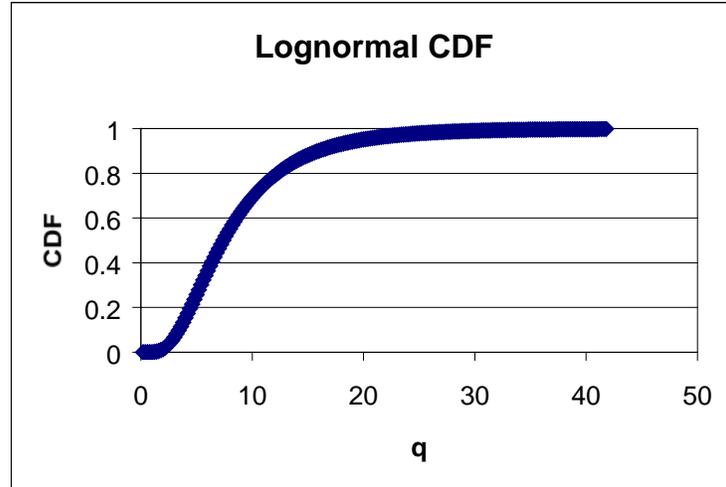
- A. Since  $q$  is lognormal,  $\ln(q)$  is normally distributed with mean  $\mu_{\ln(q)}$  and standard deviation  $\sigma_{\ln(q)}$ . These parameters can be found using Eqns. 2.48 and 2.49. You can't use the small  $V$  approximation here because  $V_q$  is 0.659 which is larger than 0.2.

$$\sigma_{\ln(q)}^2 = \ln(1 + V_q^2) = \ln\left(1 + \left(\frac{5.83}{8.85}\right)^2\right) \Rightarrow \sigma_{\ln(q)} = 0.6004$$

$$\mu_{\ln(q)} = \ln(\mu_q) - 0.5\sigma_{\ln(q)}^2 = \ln(8.85) - 0.5(0.6004)^2 = 2.000$$

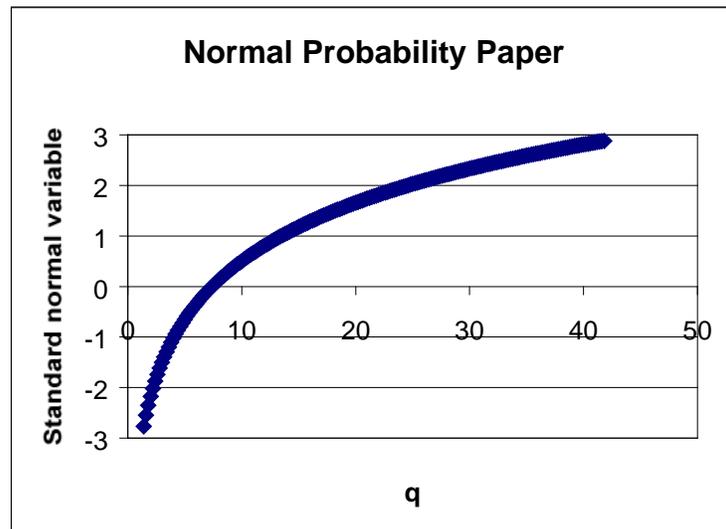
The formulas for PDF and CDF are given by Eqns. 2.52 and 2.47. Both of these can be calculated using information from the standard normal distribution.





- B. To plot the lognormal distribution on normal probability paper: (1) Calculate  $F_q(q)$  for some arbitrary values of  $q$  (in ascending order) in the range of interest.  $F_q(q)$  is the lognormal distribution, and it can be calculated as shown in Section 2.4.3. (2) Use the values of  $F_q(q_i)$  as the values of  $p_i$  for plotting points on normal probability paper. (3) Calculate  $z_i = \Phi^{-1}(p_i)$ . (4) Plot  $z_i$  versus  $q_i$  on standard linear graph paper. Since the lognormal and normal distributions are related to each other, you can show that the relationship between  $z$  and  $q$  is

$$z = \frac{\ln(q) - \mu_{\ln(q)}}{\sigma_{\ln(q)}} = \frac{\ln(q) - 2.000}{0.6004}$$



- C.

$$P(q \leq 7.39) = \Phi\left(\frac{\ln(7.39) - 2.000}{0.6004}\right) \approx \Phi(0) = 0.5$$

D.

$$\begin{aligned} P(6 \leq q \leq 8) &= \Phi\left(\frac{\ln(8) - 2.000}{0.6004}\right) - \Phi\left(\frac{\ln(6) - 2.000}{0.6004}\right) \\ &= \Phi(0.132) - \Phi(-0.346) \\ &= 0.188 \end{aligned}$$

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Problem 2.7. The yield stress of A36 steel is to be modelled as a lognormal random variable with a mean value of 36 ksi and a coefficient of variation of 10%.

- A. Plot the PDF and CDF on standard graph paper.
- B. Plot the CDF on normal probability paper.
- C. Determine the probability that the yield stress is greater than 40 ksi.
- D. Determine the probability that the yield stress is between 34 and 38 ksi.

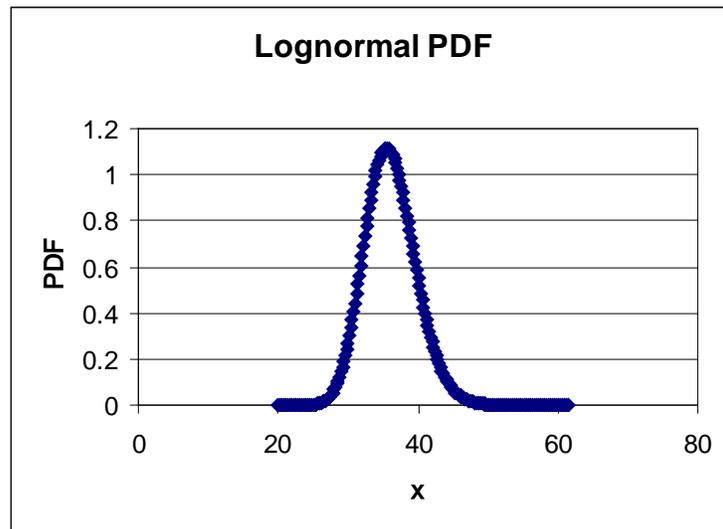
*Solution:*

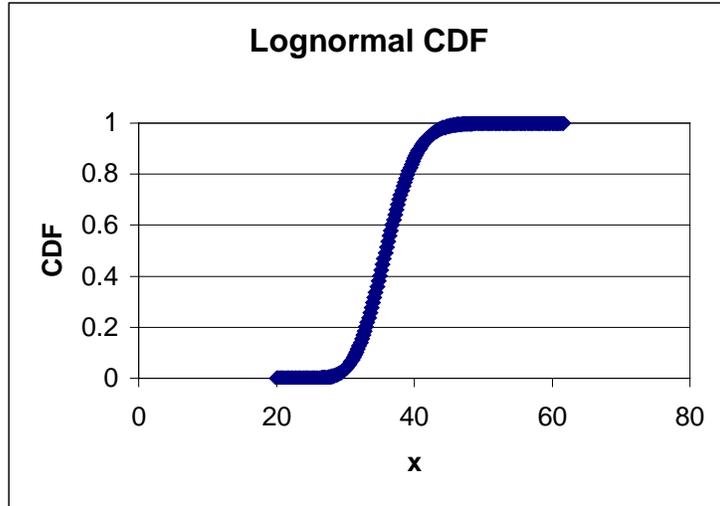
- A. Since  $X$  is lognormal,  $\ln(X)$  is normally distributed with mean  $\mu_{\ln X}$  and standard deviation  $\sigma_{\ln X}$ . These parameters can be found using Eqns. 2.48 and 2.49. We can use the small  $V$  approximation here because  $V_X$  is 0.10 which is smaller than 0.2.

$$\sigma_{\ln X}^2 = \ln(1 + V_X^2) \approx V_X^2 \Rightarrow \sigma_{\ln X} = V_X = 0.10$$

$$\mu_{\ln X} = \ln(\mu_X) - 0.5\sigma_{\ln X}^2 \approx \ln(\mu_X) = 3.584$$

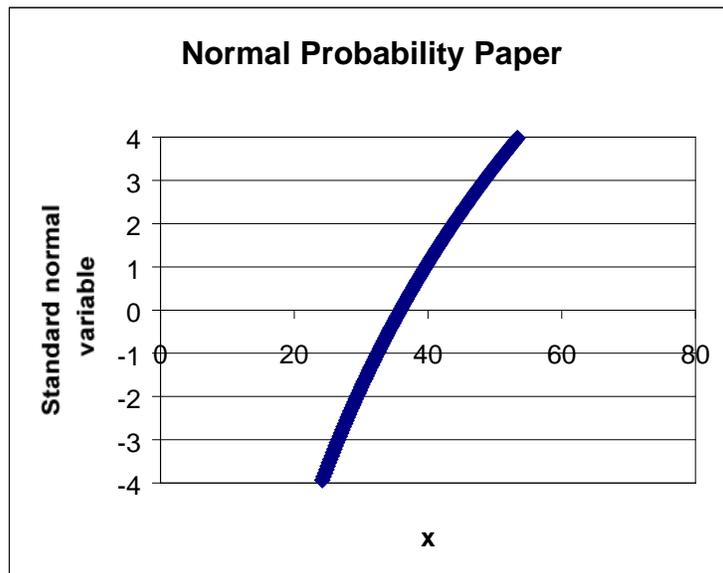
The formulas for PDF and CDF are given by Eqns. 2.52 and 2.47. Both of these can be calculated using information from the standard normal distribution.





- B. To plot the lognormal distribution on normal probability paper: (1) Calculate  $F_X(x)$  for some arbitrary values of  $x$  (in ascending order) in the range of interest.  $F_X(x)$  is the lognormal distribution, and it can be calculated as shown in Section 2.4.3. (2) Use the values of  $F_X(x_i)$  as the values of  $p_i$  for plotting points on normal probability paper. (3) Calculate  $z_i = \Phi^{-1}(p_i)$ . (4) Plot  $z_i$  versus  $x_i$ . Since the lognormal and normal distributions are related to each other, you can show that the relationship between  $z$  and  $x$  is

$$z = \frac{\ln(x) - \mu_{\ln X}}{\sigma_{\ln X}} = \frac{\ln(x) - 3.584}{0.1}$$



- C.

$$P(X > 40) = 1 - P(X \leq 40) = 1 - \Phi\left(\frac{\ln(40) - 3.584}{0.1}\right) = 1 - \Phi(1.049) = 0.147$$

D.

$$\begin{aligned} P(34 \leq X \leq 38) &= \Phi\left(\frac{\ln(38) - 3.584}{0.1}\right) - \Phi\left(\frac{\ln(34) - 3.584}{0.1}\right) \\ &= \Phi(0.536) - \Phi(-0.576) \\ &= 0.422 \end{aligned}$$

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Problem 2.8. The annual extreme wind speed at a particular location is to be modelled as an extreme Type I random variable. The mean value of the extreme wind is 50 miles per hour (mph) and the coefficient of variation is 15%.

- A. Plot the PDF and CDF on standard graph paper.
- B. Plot the CDF on normal probability paper.
- C. Determine the probability that the annual maximum wind speed is greater than 50 mph.
- D. Determine the probability that the annual maximum wind speed is less than 50 mph.
- E. Determine the probability that the wind speed will be between 40 and 60 mph.

*Solution:*

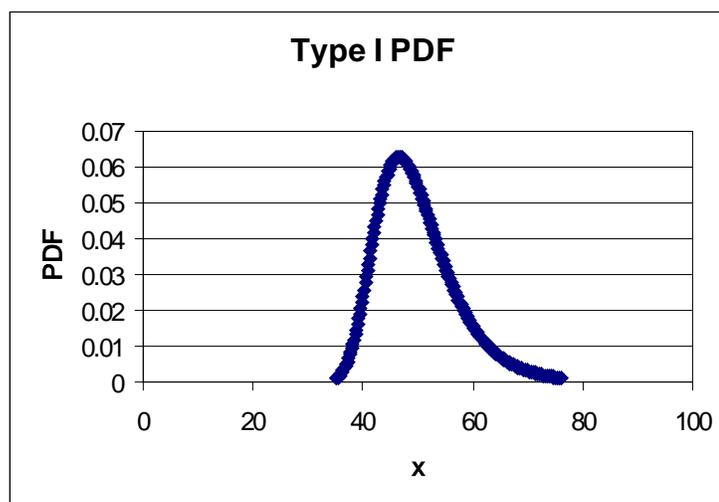
- A. Let  $X$  denote the random variable representing wind speed.

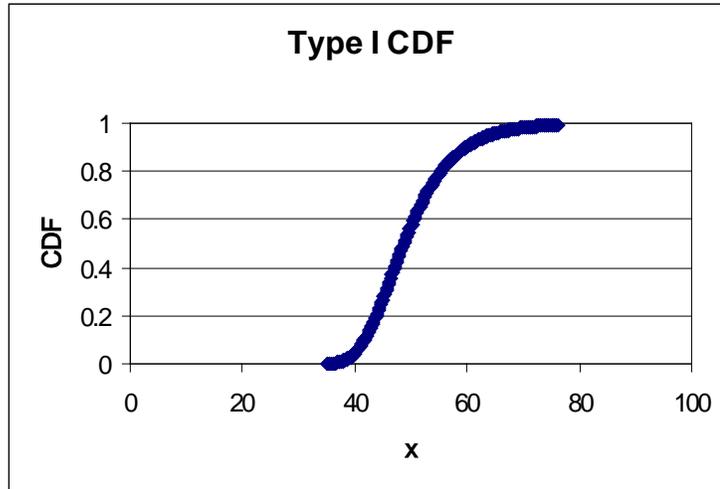
$$\mu_x = 50 \quad V_x = 0.15 \quad \Rightarrow \quad \sigma_x = V_x \mu_x = 7.5$$

To plot the PDF and CDF, we need the parameters for the Type I distribution. They can be found using Eqns. 2.62 and 2.63.

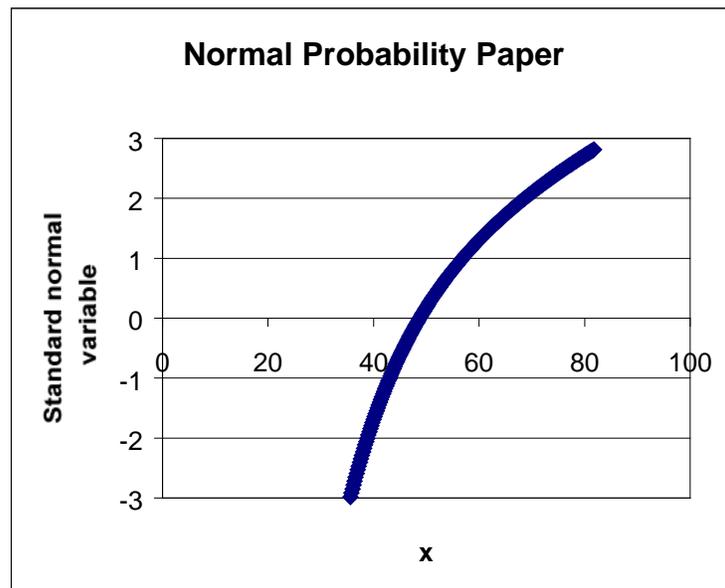
$$\alpha = \frac{1.282}{\sigma_x} = 0.1709 \quad u = \mu_x - 0.45\sigma_x = 46.63$$

The PDF and CDF functions are given by Eqns. 2.58 and 2.59.





- B. To plot the Type I CDF on normal probability paper: (1) Calculate  $F_X(x)$  for some arbitrary values of  $x$  (in ascending order) in the range of interest.  $F_X(x)$  is the Type I distribution. (2) Use the values of  $F_X(x_i)$  as the values of  $p_i$  for plotting points on normal probability paper. (3) Calculate  $z_i = \Phi^{-1}(p_i)$ . (4) Plot  $z_i$  versus  $x_i$  on standard linear graph paper.



C.

$$\begin{aligned}
 P(X > 50) &= 1 - P(X \leq 50) = 1 - F_X(50) \\
 &= 1 - \exp(-\exp(-\alpha(50 - u))) \\
 &= 1 - 0.5700 \\
 &= 0.43
 \end{aligned}$$

D.

$$\begin{aligned} P(X \leq 50) &= F_X(50) \\ &= \exp(-\exp(-\alpha(50 - u))) \\ &= 0.5700 \end{aligned}$$

E.

$$\begin{aligned} P(40 \leq X \leq 60) &= F_X(60) - F_X(40) \\ &= \exp(-\exp(-\alpha(60 - u))) - \exp(-\exp(-\alpha(40 - u))) \\ &= 0.9032 - 0.04482 = 0.8584 \end{aligned}$$

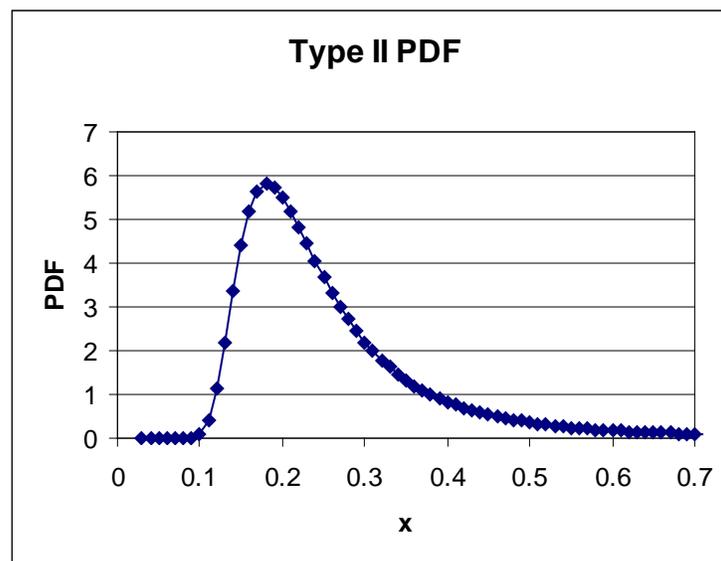
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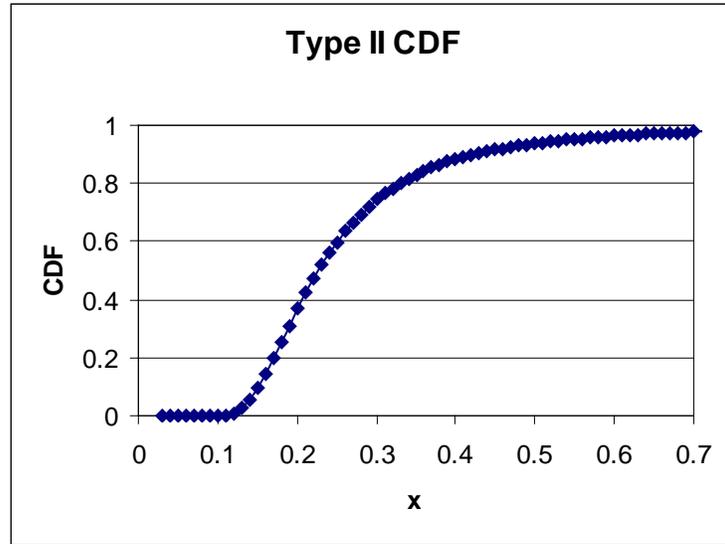
**Problem 2.9.** The peak ground acceleration  $A$  that is expected at a site in a 50 year time period is modelled as an extreme Type II random variable with  $u = 0.2g$  ( $g$  is the acceleration of gravity) and  $k = 3$ .

- A. Plot the PDF and CDF on standard graph paper.
- B. Plot the CDF on normal probability paper.
- C. Determine the probability that the ground acceleration will be between  $0.15g$  and  $0.2g$ .
- D. Determine the probability that the ground acceleration will be greater than  $0.3g$ .

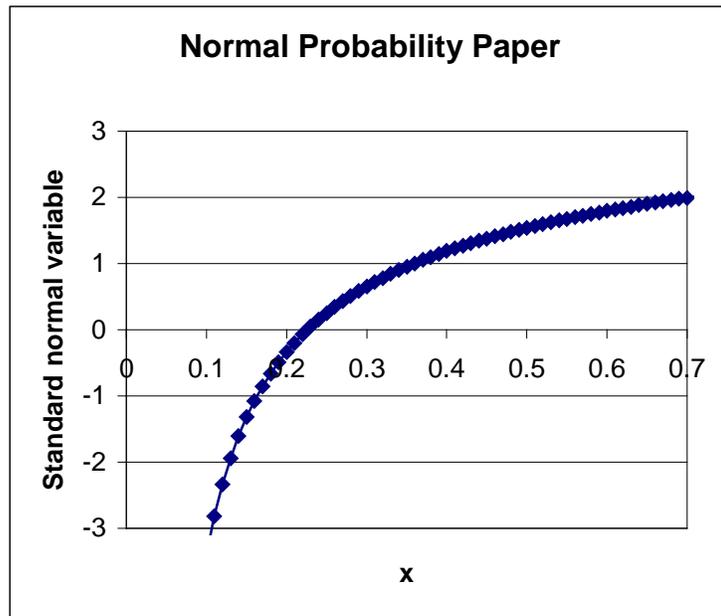
*Solution:*

- A. The parameters  $u$  and  $k$  are already known. The formulas for PDF and CDF are given in Eqns. 2.64 and 2.65.





- B. To plot the Type II CDF on normal probability paper: (1) Calculate  $F_X(x)$  for some arbitrary values of  $x$  (in ascending order) in the range of interest.  $F_X(x)$  is the Type II distribution. (2) Use the values of  $F_X(x_i)$  as the values of  $p_i$  for plotting points on normal probability paper. (3) Calculate  $z_i = \Phi^{-1}(p_i)$ . (4) Plot  $z_i$  versus  $x_i$  on standard linear graph paper.



C.

$$\begin{aligned}P(0.15 \leq A \leq 0.2) &= F_A(0.2) - F_A(0.15) \\&= \exp\left(-\left(\frac{u}{0.2}\right)^k\right) - \exp\left(-\left(\frac{u}{0.15}\right)^k\right) \\&= 0.3679 - 0.09345 \\&= 0.2745\end{aligned}$$

D.

$$\begin{aligned}P(A > 0.3) &= 1 - P(A \leq 0.3) \\&= 1 - \exp\left(-\left(\frac{u}{0.3}\right)^k\right) \\&= 1 - 0.7436 \\&= 0.2564\end{aligned}$$

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Problem 2.10. The occurrence of major snow storms (snowfall greater than 1 foot) for a particular location is assumed to follow a Poisson distribution. Over 33 years of snowfall records, such storms have occurred 94 times.

- A. What is the probability of 2 or more major storms in the next year?
- B. What is the probability of exactly 2 storms occurring in the next 3 years?
- C. What is the return period of these storms?
- D. What is the probability of more than 3 storms in the next 2 years?

*Solution:*

The average occurrence rate,  $v$ , of storms is

$$v = \frac{94}{33} = 2.85 \text{ occurrences/year}$$

- A. The time interval,  $t$ , is 1 year.

$$\begin{aligned}P(N \geq 2) &= 1 - P(N < 2) \\&= 1 - [P(N = 0) + P(N = 1)] \\&= 1 - \left[ \frac{(vt)^0}{0!} e^{-vt} + \frac{(vt)^1}{1!} e^{-vt} \right] \\&= 1 - e^{-v} - ve^{-v} \\&= 0.777\end{aligned}$$

B. The time interval,  $t$ , is 3 years.

$$\begin{aligned}P(N = 2) &= \frac{(vt)^2}{2!} e^{-vt} \\ &= \frac{[(2.85)(3)]^2}{2!} e^{-(2.85)(3)} \\ &= 7.07 \times 10^{-3}\end{aligned}$$

C. The return period is defined as the inverse of the average occurrence rate.

$$\tau = \frac{1}{v} = 0.351 \text{ years/occurrence}$$

D. The time interval,  $t$ , is 2 years.

$$\begin{aligned}P(N > 3) &= 1 - P(N \leq 3) \\ &= 1 - [P(N = 0) + P(N = 1) + P(N = 2) + P(N = 3)] \\ &= 1 - \left[ \frac{(vt)^0}{0!} e^{-vt} + \frac{(vt)^1}{1!} e^{-vt} + \frac{(vt)^2}{2!} e^{-vt} + \frac{(vt)^3}{3!} e^{-vt} \right] \\ &= 0.820\end{aligned}$$

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### SOLUTIONS TO PROBLEMS IN CHAPTER 3

Problem 3.1. Derive Equation (3.2).

*Solution:*

The simplest derivation uses the fact that the expectation operator  $E[\ ]$  is a linear operator. Therefore,

$$\begin{aligned}\mu_Y &= E[Y] = E\left[a_0 + \sum a_i X_i\right] \\ &= E[a_0] + E\left[\sum a_i X_i\right] \\ &= a_0 + \sum E[a_i X_i] \\ &= a_0 + \sum a_i E[X_i] \\ &= a_0 + \sum a_i \mu_{X_i}\end{aligned}$$

An alternate derivation uses the integral definition of expected value (Eqn. 2.28 extended to apply to a random vector) and the concept of marginal density functions (Eqn. 2.85). By the definition of expected value for a function of random variables,

$$\mu_Y = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \cdots \int_{-\infty}^{+\infty} \left[ a_0 + \sum a_i x_i \right] f_{X_1, X_2, \dots, X_n}(x_1, x_2, \dots, x_n) dx_1 dx_2 \cdots dx_n$$

where  $f_{X_1, X_2, \dots, X_n}(x_1, x_2, \dots, x_n)$  is the  $n$ -dimensional joint density function. By multiplying out terms and carrying out  $n-1$  of the integrals in each term to get to marginal density functions, we get

$$\begin{aligned}\mu_Y &= a_0 + \sum \int_{-\infty}^{+\infty} a_i x_i f_{X_i}(x_i) dx_i \\ &= a_0 + \sum a_i \mu_{X_i}\end{aligned}$$

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Problem 3.2. Derive Equation (3.3).

*Solution:*

The simplest derivation uses the fact that the expectation operator  $E[\ ]$  is a linear operator. Therefore,