Section 1

MANE 3332.04

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andouts

- Chapter 9 slides
- Chapter 9 slides marked

Decision Making for a Single Sample

- Inferential statistics consists of methods used to make decisions or draw conclusions about a population using information contained in a sample
- Inference is divided into two major areas:
  - Parameter estimation (both point and interval)
  - Hypothesis testing

Overview of Statistical Hypotheses

- Many engineering problems require a decision to be made regarding some statement about a parameter
  - The statement is called a **hypothesis**
  - The decision-making process about the hypothesis is call **hypothesis testing**
- Statistical hypothesis testing is usually the data analysis stage of a **comparative experiment**
- A procedure leading to a decision about a particular hypothesis is called a **test of hypothesis**
- Testing the hypothesis involves taking a random sample, computing a **test statistic** from the sample data and then using the to make a decision

x

x

x

Overview of Statistical Hypotheses

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Null Hypothesis

$H_0 : N = value$

$H_1 : \begin{cases} N \neq value \\ N < value \\ N > value \end{cases}$

Court

$H_0 :$ accused is innocent

$H_1 :$ Accused is Not innocent

Skip this for a while

Chapter 9 Page 5

tatistical Hypothesis

- A **statistical hypothesis** is a statement about the parameters of one or more populations
- A statistical hypothesis has two parts a null hypothesis (denoted H_0) and an alternative hypothesis (denoted H_1)
    - The null hypothesis contains an equality statement about the value of parameter. For example $H_0 : \mu = 12$ ounces.
    - There are three possible alternative hypotheses: $H_1 : \mu \neq 12$, $H_1 : \mu < 12$, or $H_1 : \mu > 12$
    - The goal of the research will determine the appropriate alternative hypothesis

Cases 1 & 2

mean of normal

μ

2-sided

lower

upper

Case 3

Std. dev. or variance of normal

σ σ σ^2

Summary of One-Sample Hypothesis-Testing Procedures

Case	Null Hypothesis	Test Statistic	Alternative Hypothesis
1.	$H_0 : \mu = \mu_0$ σ^2 known	$z_0 = \dfrac{\bar{x} - \mu_0}{\sigma/\sqrt{n}}$	$H_1 : \mu \neq \mu_0$ $H_1 : \mu > \mu_0$ $H_1 : \mu < \mu_0$

Chapter 8, Case 1

$$\bar{x} - z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \leq \mu \leq \bar{x} + z_{\alpha/2}\frac{\sigma}{\sqrt{n}}$$

rrors in hypothesis testing

- Whether a correct decision is made depends upon the true nature of H_0 and the decision arrived at.
- A **type I error** occurs when the null hypothesis is true and the outcome of the test is to reject H_0. The probability of a type I error is denoted as α
- A **type II error** occurs when the null hypothesis is false and the outcome of the test is to fail to reject H_0. The probability of a type II error is denoted as β.
- The **power** of a statistical test is the probability rejecting the null hypothesis H_0 when the alternative hypothesis is true. Power $= 1 - \beta$

Reject H_0 Fail to Reject H_0 Reject H_0
$\mu \neq 50$ cm/s $\mu = 50$ cm/s $\mu \neq 50$ cm/s

48.5   50   51.5

Figure 9-1 Decision criteria for testing H_0: $\mu = 50$ centimeters per second versus H_1: $\mu \neq 50$ centimeters per second.

Table 9-1 Decisions in Hypothesis Testing

Decision	H_0 Is True	H_0 Is False
Fail to reject H_0	no error	type II error
Reject H_0	type I error	no error

Procedure

1) Fail to reject Ho } Decisions
2) Reject Ho

Know 2 things
1) Decision
2) Ho true or false

Ho: Person is healthy
H1: person is not healthy (sick)

True Nature of Ho

Decision	Ho True	Ho False
Fail to Reject Ho	✓	type II error
Reject Ho	type I error	✓

type I error: healthy person is told they are sick
type II error: Sick person is told they are healthy

rror Example: Manufacturing

rror Example: Medical

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eneral Procedure for Hypothesis Testing

he following sequence of steps is recommended
1. From the problem context, identify the parameter of interest,
2. State the null hypothesis, H_0,
3. Specify an appropriate alternative hypothesis, H_1,
4. Choose a significance level α
5. State an appropriate test statistic,
6. State the rejection region for the (test) statistic,
7. Compute any necessary sample quantities, substitute these into the equation for the test statistics, and compute that value,
8. Decide whether or not H_0 should be rejected and report in the problem context

iference on the Mean of a population, variance known

- Assumptions:
    1. $X_1, X_2, \ldots, X_n$ is a random sample of size n from a population
    2. The population is normal, or if it is not normal, the conditions of the central limit theorem apply
- The parameter of interest is μ
- The null hypothesis is $H_0 : \mu = \mu_0$
- The test statistic is

$$Z_0 = \frac{\overline{X} - \mu_0}{\sigma/\sqrt{n}}$$

nd has a standard normal distribution

- The alternative hypotheses and corresponding critical value(s) are shown in figure 9-11 on page 209
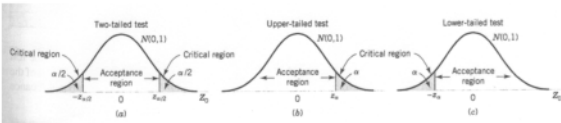
FIGURE 9.11
The distribution of Z_0 when $H_0: \mu = \mu_0$ is true with critical region for (a) the two-sided alternative $H_1: \mu \neq \mu_0$, (b) the one-sided alternative $H_1: \mu > \mu_0$, and (c) the one-sided alternative $H_1: \mu < \mu_0$.

Summary for hypothesis test on the mean, variance known

- See the material on the inside cover of your textbook

Summary of One-Sample Hypothesis Testing Procedures

Null Hypothesis	Test Statistic	Alternative Hypothesis	Fixed Significance Level Criteria for Rejection	P-Value	O.C. Curve Parameter	O.C. Curve Appendix Chart VII
$H_0: \mu = \mu_0$ σ^2 known	$z_0 = \dfrac{\bar{x} - \mu_0}{\sigma/\sqrt{n}}$	$H_1: \mu \neq \mu_0$	$|z_0| > z_{\alpha/2}$	$P = 2[1 - \Phi(|z_0|)]$	$d = |\mu - \mu_0|/\sigma$	a, b
		$H_1: \mu > \mu_0$	$z_0 > z_\alpha$	Probability above z_0 $P = 1 - \Phi(z_0)$	$d = (\mu - \mu_0)/\sigma$	c, d
		$H_1: \mu < \mu_0$	$z_0 < -z_\alpha$	Probability below z_0 $P = \Phi(z_0)$	$d = (\mu_0 - \mu)/\sigma$	c, d

(handwritten annotations)

① ②

Rejection Region

absolute value of z_0

d is the same as

To find β using tables

$\alpha = .05$
$\alpha = .01$

Reject H_0 if
P-value $< \alpha$
Else (if P-value $> \alpha$)
fail to reject H_0

Example 11-1

The burning rate of a rocket propellant is being studied. Specifications require that the mean burning rate must be 40 cm/s. Furthermore, suppose that we know that the standard deviation of the burning rate is approximately 2 cm/s. The experimenter decides to specify a type I error probability $\alpha = 0.05$, and he will base the test on a random sample of size $n = 25$. The hypotheses we wish to test are

$$H_0: \mu = 40 \text{ cm/s.}$$
$$H_1: \mu \neq 40 \text{ cm/s.}$$

Twenty-five specimens are tested, and the sample mean burning rate obtained is $\bar{x} = 41.25$ cm/s.

Source: Hines, Montgomery, Goldsman, Borror (2003). Probability and Statistics in Engineering, 4th ed.

① $\sigma = 2$
$\alpha = .05$
$n = 25$

$H_0: \mu_1 = 40$
$H_1: \mu_2 \neq 40$

② Test Statistic

$$Z_0 = \frac{\bar{X} - \mu_0}{\sigma/\sqrt{n}} = \frac{41.25 - 40}{2/\sqrt{25}}$$

$$= 3.125$$

③ Rejection Region (tied to H_1)

Reject H_0 if $|Z_0| > Z_{\alpha/2}$

$Z_{.05/2} = Z_{.025}$
$= 1.96$

-1.96 1.96
$Z_0 = 3.125$
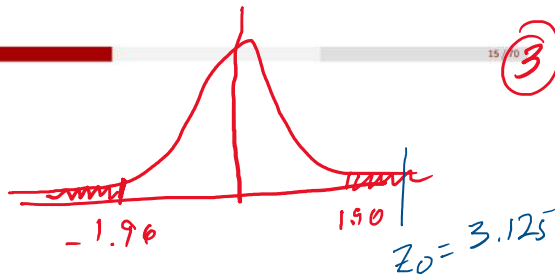
classical Approach
Fixed Rejection Region

④ Conclusion:
Since $Z_0 > Z_{\alpha/2}$, we reject the null hypothesis.
The mean burn is different from 40 cm/s at an .05 significance level.

9.2.10 The bacterial strain *Acinetobacter* has been tested for its adhesion properties. A sample of five measurements gave readings of 2.69, 5.76, 2.67, 1.62 and 4.12 dyne-cm². Assume that the standard deviation is known to be 0.66 dyne-cm² and that the scientists are interested in high adhesion (at least 2.5 dyne-cm²).

a. Should the alternative hypothesis be one-sided or two-sided?

b. Test the hypothesis that the mean adhesion is 2.5 dyne-cm².

c. What is the *P*-value of the test statistic?

ummary Statistics

```
<-c(2.69,5.76,2.67,1.26,4.12)
ibrary(psych)
escribe(x)

#     vars n mean   sd median trimmed  mad  min  max range skew kurtosis   se
# X1      1 5  3.3 1.71   2.69     3.3 2.12 1.26 5.76  4.5 0.26    -1.71 0.76
```

$\sigma = .66$

$\alpha = .05$

① $H_0: \mu = 2.5$

$H_1: \mu > 2.5$

$\neq$
$\leq$
$>$

② Test Statistic

$$Z_0 = \frac{\bar{X} - \mu_0}{\sigma/\sqrt{n}} = \frac{3.3 - 2.5}{.66/\sqrt{5}} = 2.71$$

③ Rejection Region

Reject H_0 if $Z_0 > Z_\alpha = Z_{.05} = 1.645$

④ Conclusion: Reject H_0

Since $Z_0 > Z_\alpha$

Rejection Region

1.645 $Z_0 = 2.71$
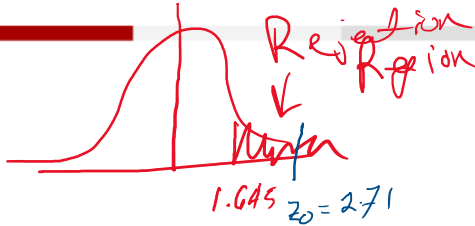
onnection between Hypothesis Tests and CI

- There is a close connection between confidence intervals and hypothesis tests
- Consider a $100(1 - \alpha)\%$ confidence interval on μ and a hypothesis test of size α shown below

$$H_0 : \mu = \mu_0$$
$$H_1 : \mu \neq \mu_0$$

- The conclusion to reject H_0 will be reached if μ_0 is not contained within the confidence interval
- If μ_0 is within the confidence interval, we fail to reject H_0
- The $100(1 - \alpha)\%$ confidence interval on μ is the acceptance region

Confidence interval is the same as the acceptance region in a Statistical hypothesis test

- Is a widely used alternative to the traditional hypothesis test
- Definition: The p-value is the smallest level of significance that would lead to reject of the null hypothesis H_0 with the given data
- Formulas are given below

$$P = \begin{cases} 2[1 - \Phi(|z_0|)] & \text{for a two-tailed test} \\ 1 - \Phi(z_0) & \text{for a upper-tailed test} \\ \Phi(z_0) & \text{for a lower-tailed test} \end{cases}$$

- Usage: if p-value$<\alpha$ then the conclusion is reject H0, otherwise fail to reject H0

Test 1 - continuation ($\mu > 2.5$)

$z_0 = 1.64$

Conclusion: fail to reject Ho

Test 2

$z_0 = 1.65$

Conclusion: reject Ho

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ractice Problem Chapter 9, Case 1 Lower

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$\beta = f(\delta, \sigma, n, \alpha)$

ype II error and sample size for a two-tailed test

- Probability of type II error for the two-tailed test

$$\beta = \Phi\left(z_{\alpha/2} - \frac{\delta\sqrt{n}}{\sigma}\right) - \Phi\left(-z_{\alpha/2} - \frac{\delta\sqrt{n}}{\sigma}\right)$$

here $\mu = \mu_0 + \delta$

- The sample to detect a difference between the true and hypothesized mean of δ with power at least $1 - \beta$ is

$$n \approx \frac{(z_{\alpha/2} + z_\beta)^2 \sigma^2}{\delta^2}$$

here $\delta = \mu - \mu_0$

not on final;
don't add to
these cards

ype II error and sample size for the one-tailed tests

- For an upper-tailed test

$$\beta = \Phi \left(z_\alpha - \frac{\delta \sqrt{n}}{\sigma} \right)$$

- For a lower-tailed test

$$\beta = 1 - \Phi \left(-z_\alpha - \frac{\delta \sqrt{n}}{\sigma} \right)$$

- The sample size required to detect a difference between the true mean and hypothesized mean of δ with power at least $1 - \beta$ is

$$n = \frac{(z_\alpha + z_\beta)^2 \sigma^2}{\delta^2}$$

n is not an integer, round up to the nearest integer

Same thing as Previous slide

case 1, type 2 error calculations

Z-test

```
library(BSDA)

## Loading required package: lattice

##
## Attaching package: 'BSDA'

## The following object is masked from 'package:datasets':
##
##    Orange

z.test(x,alternative='greater',mu=2.5,sigma.x=0.66,conf.level=0.95)

##
##  One-sample z-Test
##
## data:  x
## z = 2.7104, p-value = 0.00336
## alternative hypothesis: true mean is greater than 2.5
## 95 percent confidence interval:
##  2.814503      NA
## sample estimates:
## mean of x
##       3.3
```

$H_1 : \mu > \mu_0$ → chapter 9, Case 1

$1 - \alpha$

→ Test statistic

← Confidence Bound

ind the power when the true mean value is 3.325

β = .43
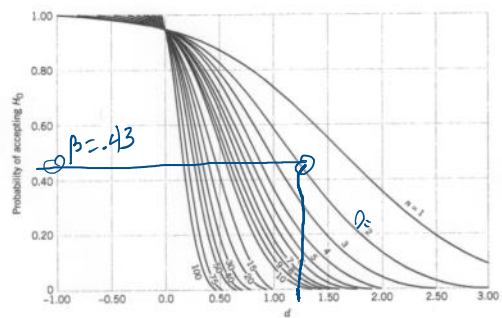
d = 1.25
n = 2

```
library(asbio)

## Warning: package 'asbio' was built under R version 4.2.3

## Loading required package: tcltk

##
## Attaching package: 'asbio'

## The following object is masked from 'package:psych':
##
##     skew

power.z.test(sigma=0.66,n=5,alpha=0.05,effect=0.825,test="one.tail")

## $sigma
## [1] 0.66
##
## $n
## [1] 5
##
## $power
## [1] 0.8749757
##
## $alpha
## [1] 0.05
##
## $effect
## [1] 0.825
##
## $test
```

Handwritten annotations: σ, n, α, d above the highlighted line; "Five Facts"; "1-β"

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ype II Error Rate and Sample Size

- You will not be required to calculate or use OC-curves
- You must understand the concept and be able to correctly identity type I and type II error

Table 9-1

decision

H₀ True | H₀ False

for all cases

ypothesis Test on the Mean, Variance Unknown

- Much more common case than variance known
- Substitute S for σ
- The test statistics is now a t random variable

$$T = \frac{\overline{X} - \mu_0}{S/\sqrt{n}}$$

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"Practical" Case

Mean & Variance are unknown

If $X_1, \ldots, X_n$ are independent Samples from normal distribution

$T = \frac{\overline{X} - \mu_0}{S/\sqrt{n}}$ has a t distribution with $n-1$ degrees of freedom

ummary of Case 2

Handwritten annotations: Rejection Regions, P-values, OC-Curve, B

$H_0: \mu = \mu_0$ σ^2 unknown	$t_0 = \dfrac{\bar{x} - \mu_0}{s/\sqrt{n}}$	$H_1: \mu \neq \mu_0$	$|t_0| > t_{\alpha/2, n-1}$	Sum of the probability above $|t_0|$ and below $-|t_0|$	$d = |\mu - \mu_0|/\sigma$	e, f
		$H_1: \mu > \mu_0$	$t_0 > t_{\alpha, n-1}$	Probability above t_0	$d = (\mu - \mu_0)/\sigma$	g, h
		$H_1: \mu < \mu_0$	$t_0 < -t_{\alpha, n-1}$	Probability below t_0	$d = (\mu_0 - \mu)/\sigma$	g, h

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9.3.6 An article in the *ASCE Journal of Energy Engineering* (1999, Vol. 125, pp. 59–75) describes a study of the thermal inertia properties of autoclaved aerated concrete used as a building material. Five samples of the material were tested in a structure, and the average interior temperatures (°C) reported were as follows: 23.01, 22.22, 22.04, 22.62, and 22.59.

a. Test the hypotheses H_0: $\mu = 22.5$ versus H_1: $\mu \neq 22.5$, using $\alpha = 0.05$. Find the *P*-value.

b. Check the assumption that interior temperature is normally distributed.

c. Compute the power of the test if the true mean interior temperature is as high as 22.75.

d. What sample size would be required to detect a true mean interior temperature as high as 22.75 if you wanted the power of the test to be at least 0.9?

e. Explain how the question in part (a) could be answered by constructing a two-sided confidence interval on the mean interior temperature.
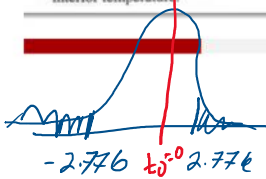
① $H_0 : \mu = 22.5$

$H_1 : \mu \neq 22.5$ ←

② Test Statistic

$t_0 = \dfrac{\bar{X} - \mu_0}{S/\sqrt{n}}$ ($\mu_0 = 22.5, n = 5$)

$= \dfrac{22.5 - 22.5}{.38/\sqrt{5}} = 0.0$

③ Rejection Region

Reject H_0 if $|t_0| > t_{\alpha/2, n-1} = t_{.025, 4}$
$= 2.776$

④ Conclusion
Fail to reject H_0

$-2.776 \quad t_0 = 0 \quad 2.776$

Descriptive Statistics

```
x<-c(23.01,22.22,22.04,22.62,22.59)
library(psych)
describe(x)

##    vars n mean   sd median trimmed  mad   min   max range skew kurtosis
se
## X1    1 5 22.5 0.38  22.59    22.5 0.55 22.04 23.01  0.97 0.08    -1.84
0.17
```
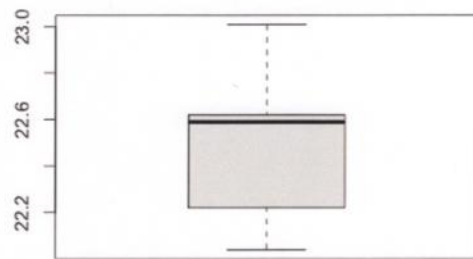
Boxplot

```
boxplot(x)
```

lassical Approach

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ypothesis Test Using R

t-test

```
t.test(x,alternative="two.sided",mu=22.5,conf.level=0.95)

##
##  One Sample t-test
##
## data:  x
## t = -0.023642, df = 4, p-value = 0.9823
## alternative hypothesis: true mean is not equal to 22.5
## 95 percent confidence interval:
##  22.02625 22.96575
## sample estimates:
## mean of x
##    22.496
```

No   1-α

← c.i. contains 22.5

ormal Probability Plot
```
brary(car)
I Loading required package: carData
I
I Attaching package: 'car'
I The following object is masked from 'package:psych':
I
I     logit
Plot(x)
```
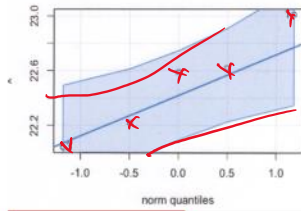

H_0: Data is normal

H_1: Data is not normal

if all points are within the bounds, then fail to reject H_0 (data is normal)

-values

- More difficult to calculate since the t-tables only contain a few quantiles
- Can use tables to generate bounds on the p-value
- Software will provide p-values

-values from R

t-test

```
t.test(x,alternative="two.sided",mu=22.5,conf.level=0.95)

##
##  One Sample t-test
##
## data:  x
## t = -0.023642, df = 4, p-value = 0.9823
## alternative hypothesis: true mean is not equal to 22.5
## 95 percent confidence interval:
##  22.02625 22.96575
## sample estimates:
## mean of x
##    22.496
```

ower Calculations

- Are much more complicated
- The true distribution is now a non-central t
- Use tables to solve (Chart VII in appendix) or software

Power Calculation using R

Power

```
power.t.test(n=5,delta=0.25,sd=0.38,sig.level=0.05,type="two.sample")

##
##      Two-sample t test power calculation
##
##              n = 5
##          delta = 0.25
##             sd = 0.38
##      sig.level = 0.05
##          power = 0.1491624          1-β
##    alternative = two.sided
##
## NOTE: n is number in *each* group
```

Sample Size using R

Sample Size

```r
power.t.test(power=0.9,delta=0.25,sd=0.38,sig.level=0.05,type="two.sample")

#
#        Two-sample t test power calculation
#
#              n = 49.53305
#          delta = 0.25
#             sd = 0.38
#      sig.level = 0.05
#          power = 0.9
#    alternative = two.sided
#
# NOTE: n is number in *each* group
```

→ 50

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ase 3. Hypothesis Test on Variance of Normal Population

- The test statistics is a χ^2 random variable

$$\chi_0^2 = \frac{(n-1)S^2}{\sigma_0^2}$$

Tests on the Variance of a Normal Distribution

Null hypothesis: $H_0: \sigma^2 = \sigma_0^2$

Test statistic: $\chi_0^2 = \frac{(n-1)S^2}{\sigma_0^2}$

Alternative Hypothesis	Rejection Criteria
$H_1: \sigma^2 \neq \sigma_0^2$	$\chi_0^2 > \chi_{\alpha/2, n-1}^2$ or $\chi_0^2 < \chi_{1-\alpha/2, n-1}^2$
$H_1: \sigma^2 > \sigma_0^2$	$\chi_0^2 > \chi_{\alpha, n-1}^2$
$H_1: \sigma^2 < \sigma_0^2$	$\chi_0^2 < \chi_{1-\alpha, n-1}^2$

$H_0: \sigma = \sigma_0$
$H_1: \sigma = \sigma_0$
$H_1: \sigma < \sigma_0$

lower $\alpha/2$

upper $\alpha/2$

$\chi_{1-\alpha/2, n-1}^2$ $\chi_{\alpha/2, n-1}^2$
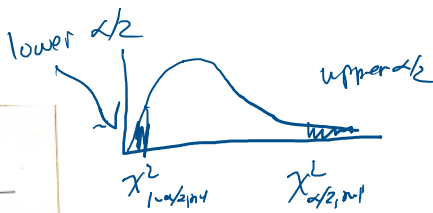
The table below summarizes the three possible hypothesis tests. The ejection regions are clearly shown in Figure 9-17 on page 222
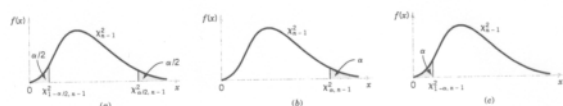
FIGURE 9.17

Reference distribution for the test of H_0: $\sigma^2 = \sigma_0^2$ with critical region values for (a) H_1: $\sigma^2 \neq \sigma_0^2$, (b) H_1: $\sigma^2 > \sigma_0^2$, and (c) H_1: $\sigma^2 < \sigma_0^2$.

est Summary

Test statistic *Rejection Region* *P-values* *OC-curve*

- See summary in your textbook

omit

not covered

$H_0: \sigma^2 = \sigma_0^2$	$\chi_0^2 = \frac{(n-1)s^2}{\sigma_0^2}$	$H_1: \sigma^2 \neq \sigma_0^2$	$\chi_0^2 > \chi_{\alpha/2, n-1}^2$ or $\chi_0^2 < \chi_{1-\alpha/2, n-1}^2$	See text Section 9.4.	$\lambda = \sigma/\sigma_0$	i, j
		$H_1: \sigma^2 > \sigma_0^2$	$\chi_0^2 > \chi_{\alpha, n-1}^2$		$\lambda = \sigma/\sigma_1$	k, l
		$H_1: \sigma^2 < \sigma_0^2$	$\chi_0^2 < \chi_{1-\alpha, n-1}^2$		$\lambda = \sigma/\sigma_1$	

roblem 7.108

roblem taken from Ostle, Turner, Hicks and McElrath (1996). *Engineering tatistics: The Industrial Experience.* Duxbury Press.

.108 Incoming coal at a coking plant is routinely analyzed for sulfur content (in percent). In the past, samples taken from barges loaded with coal from a particular mine have had a variance of 0.000196. When a new analyst was hired, the results of an assay of coal from the mine produced percentages of 0.83, 0.79, 0.77, 0.81, and 0.80.
   (a) Using α = 0.05, does the sample variance provide sufficient evidence to conclude that the results from the new analyst indicate more variability than in the past? State all assumptions.
   (b) Based on these data, is an assumption of normality reasonable? Justify by using a normal quantile plot *and* a formal test such as the Shapiro-Wilk *W* test.

$H_0: \sigma^2 = 0.000196$

$H_1: \sigma^2 > 0.000196$

Test statistic

$$\chi_0^2 = \frac{(n-1)S^2}{\sigma_0^2}$$

$$= \frac{(5-1)(.022361)^2}{.000196}$$

$$= \cancel{10.0} \; 10.204$$

$n = 5$

$\sigma_0^2 = .000196$

$S^2 \rightarrow$ from excel

Reject H_0 if $\chi_0^2 > \chi_{\alpha, n-1}^2$
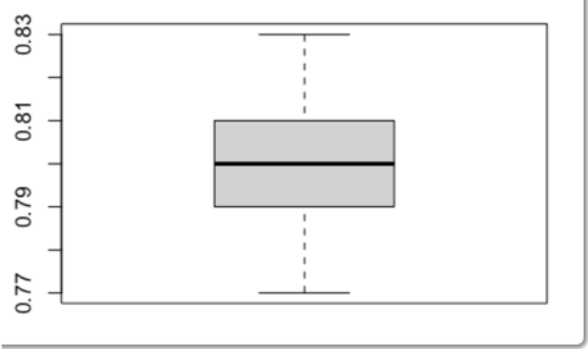
$$\chi_0^2 > \chi_{.05, 5-1}^2 = 9.49$$
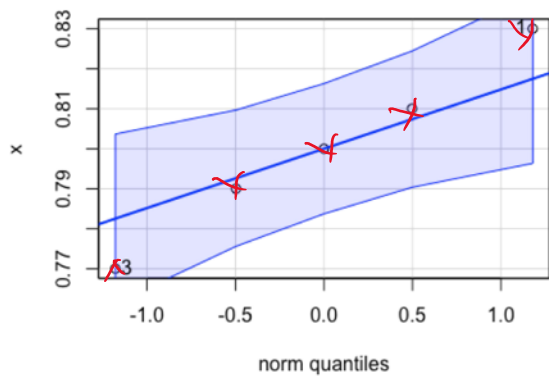
Conclusion: Since $\chi_0^2 > 9.49$, we reject H_0

tatistics for Problem 7.108

```
<-c(0.83,0.79,0.77,0.81,0.80)
ibrary(psych)
escribe(x)

#    vars n mean   sd median trimmed  mad  min  max range skew kurtosis   se
# X1    1 5  0.8 0.02    0.8     0.8 0.01 0.77 0.83  0.06    0    -1.69 0.01

rint(var(x))

# [1] 5e-04
```

lassical Approach

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H_0: data is normal

H_1: data is Not normal

Rejection Region

Reject H_0 if one or more points are outside the Confidence ($\alpha = .05$)

Conclusion: fail to reject $H_0 \longrightarrow$ data is from normal distribution

Problem 7.108 Shapiro-Wilks Test

```
# [1] 3 1

shapiro.test(x)

#
#   Shapiro-Wilk normality test
#
# data:  x
# W = 0.99929, p-value = 0.9998
```

- Very similar to the case for the mean of a normal population with variance unknown
- Difficult to calculate since the χ^2-tables only contain a few quantiles
- Can use tables to generate bounds on the p-value
- Software will provide p-values

```
VarTest(x,alternative="greater",conf.level=0.95,sigma.squared=0.000196)

#
# Results of Hypothesis Test
# --------------------------
#
# Null Hypothesis:              variance = 0.000196
#
# Alternative Hypothesis:       True variance is greater than 0.000196
#
# Test Name:                    Chi-Squared Test on Variance
#
# Estimated Parameter(s):       variance = 5e-04
#
# Data:                         x
#
# Test Statistic:               Chi-Squared = 10.20408
#
# Test Statistic Parameter:     df = 4
#
# P-value:                      0.03712675
#
# 95% Confidence Interval:      LCL = 0.0002107986
#                               UCL =        Inf
```

ower Calculations

- Can be done with OC curves found in Table VIIi–n
- Can be done in software such as R

Test on Standard Deviation

- What about test on standard deviation?

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ractice Problem Chapter 9, Case 3 Lower

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ractice Problem Chapter 9, Case 3 Upper

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ase 4. Hypothesis Test on a Population Proportion

p from Binomial Distribution

- The test statistics for the hypothesis test is

$$Z_0 = \frac{x - np_0}{\sqrt{np_0(1 - p_0)}}$$

→ reserved for Standard Normal

$H_0: p = p_0$	$z_0 = \dfrac{x - np_0}{\sqrt{np_0(1 - p_0)}}$	$H_1: p \neq p_0$	$\lvert z_0 \rvert > z_{\alpha/2}$	$p = 2[1 - \Phi(z_0)]$	3-4	3-4
		$H_1: p > p_0$	$z_0 > z_\alpha$	Probability above z_0 $p = 1 - \Phi(z_0)$	3-4	3-4
		$H_1: p < p_0$	$z_0 < -z_\alpha$	Probability below z_0 $P = \Phi(z_0)$	3-4	3-4

No Problems from Chapters 8 & 9, Case 4

9.5.2 WP Suppose that of 1000 customers surveyed, 850 are satisfied or very satisfied with a corporation's products and services.

    a. Test the hypothesis H_0: $p = 0.9$ against H_1: $p \neq 0.9$ at $\alpha = 0.05$. Find the P-value.

    b. Explain how the question in part (a) could be answered by constructing a 95% two-sided confidence interval for p.

roblem 9.5.2 Classic Approach

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ower Calculations

Ignore

- For the two-sided alternative hypothesis

$$\beta = \quad \Phi\left(\frac{p_0 - p + z_{\alpha/2}\sqrt{p_0(1-p_0)/n}}{\sqrt{p(1-p)/n}}\right)$$

$$-\Phi\left(\frac{p_0 - p - z_{\alpha/2}\sqrt{p_0(1-p_0)/n}}{\sqrt{p(1-p)/n}}\right)$$

- If the alternative is $H_1 : p < p_0$

$$\beta = 1 - \Phi\left(\frac{p_0 - p - z_{\alpha}\sqrt{p_0(1-p_0)/n}}{\sqrt{p(1-p)/n}}\right)$$

- and finally if the alternative hypothesis is $H_1 : p > p_0$

$$\beta = \Phi\left(\frac{p_0 - p + z_{\alpha}\sqrt{p_0(1-p_0)/n}}{\sqrt{p(1-p)/n}}\right)$$

ample Size

Ignore

- Sample size requirements to satisfy type II(β) error constraints for a two-tailed hypothesis test is given by

$$n = \left[\frac{z_{\alpha/2}\sqrt{p_0(1 - p_0)} + z_\beta \sqrt{p(1 - p)}}{p - p_0} \right]^2.$$

- For a sample size for a one-sided test substitute z_α for $z_{\alpha/2}$.
- Problem 9.95

esting for Goodness of Fit

- Material is presented in section 9-7 of your textbook
- Procedure determines if the sample data is from a specified underlying distribution
- Procedure uses a χ^2 distribution
- Example 9-12 presents a χ^2 goodness of fit test for a Poisson example
- Example 9-13 presents a χ^2 goodness of fit test for a normal example

rocedure

1. Collect a random sample of size n from a population with an unknown distribution,
2. Arrange the n observations in a frequency distribution containing k classes
3. Calculate the observed frequency in each class O_i,
4. From the hypothesized distribution, calculate the expected frequency in class i, denoted E_i (if E_i is small combine classes)
5. Calculate the test statistic

$$\chi_0^2 = \frac{\sum_{i=1}^k (O_i - E_i)^2}{E_i}$$

6. Reject the null hypothesis if the calculated value of the test statistic $\chi_0^2 > \chi_{\alpha, k-p-1}^2$ where p is the number of parameters in the hypothesized distribution

Brief overview

1) Observed values

2) Calculate statistics from observed samples

3) Calculate Expected values using parameter estimated from 2)

EXAMPLE 9.12 | Printed Circuit Board Defects—Poisson Distribution

The number of defects in printed circuit boards is hypothesized to follow a Poisson distribution. A random sample of $n = 60$ printed circuit boards has been collected, and the following number of defects observed.

Number of Defects	Observed Frequency
0	32
1	15
2	9
×72	4

The mean of the assumed Poisson distribution in this example is unknown and must be estimated from the sample data. The estimate of the mean number of defects per board is the sample average, that is, $(32 \cdot 0 + 15 \cdot 1 + 9 \cdot 2 + 4 \cdot 3)/60 = 0.75$. From the Poisson distribution with parameter 0.75, we may compute p_i, the theoretical, hypothesized probability associated with the ith class interval. Because each class interval corresponds to a particular number of defects, we may find the p_i as follows:

$$p_1 = P(X = 0) = \frac{e^{-0.75}(0.75)^0}{0!} = 0.472$$

$$p_2 = P(X = 1) = \frac{e^{-0.75}(0.75)^1}{1!} = 0.354$$

$$p_3 = P(X = 2) = \frac{e^{-0.75}(0.75)^2}{2!} = 0.133$$

$$p_4 = P(X \geq 3) = 1 - (p_1 + p_2 + p_3) = 0.041$$

The expected frequencies are computed by multiplying the sample size $n = 60$ times the probabilities p_i. That is, $E_i = np_i$. The expected frequencies follow:

Number of Defects	Probability	Expected Frequency
0	0.472	28.32
1	0.354	21.24
2	0.133	7.98
3 (or more)	0.041	2.46

Because the expected frequency in the last cell is less than 3, we combine the last two cells:

Number of Defects	Observed Frequency	Expected Frequency
0	32	28.32
1	15	21.24
2 (or more)	13	10.44

The seven-step hypothesis-testing procedure may now be applied, using $\alpha = 0.05$, as follows:

1. **Parameter of interest:** The variable of interest is the form of the distribution of defects in printed circuit boards.

2. **Null hypothesis:** H_0: The form of the distribution of defects is Poisson.

3. **Alternative hypothesis:** H_1: The form of the distribution of defects is not Poisson.

4. **Test statistic:** The test statistic is $\chi_0^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$

5. **Reject H_0 if:** Because the mean of the Poisson distribution was estimated, the preceding chi-square statistic will have $k - p - 1 = 3 - 1 - 1 = 1$ degree of freedom. Consider whether the P-value is less than 0.05.

6. **Computations:**

$$\chi_0^2 = \frac{(32 - 28.32)^2}{28.32} + \frac{(15 - 21.24)^2}{21.24} + \frac{(13 - 10.44)^2}{10.44}$$
$$= 2.94$$

7. **Conclusions:** We find from Appendix Table III that $\chi_{0.10,1}^2 = 2.71$ and $\chi_{0.05,1}^2 = 3.84$. Because $\chi_0^2 = 2.94$ lies between these values, we conclude that the P-value is between 0.05 and 0.10. Therefore, because the P-value exceeds 0.05, we are unable to reject the null hypothesis that the distribution of defects in printed circuit boards is Poisson. The exact P-value computed from software is 0.0864.

4-28 Attendance : 1-C

hapter 9 Summary

- You should be prepared to work any practice problems assigned: Cases 1-3 with three different alternatives
- All other information is conceptual knowledge that can be questioned with multiple choice
  - Name 3 ways to test if data is from a normal distribution

1) Probability Plotting
2) χ^2 goodness of fit
3) Wilks-Shapiro (non-parametric)

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Chapter 9, case 1 2-sided

Monday, April 21, 2025   8:31 AM

Calculate the test statistic for a test of hypothesis for the mean of single sample with variance known. The null hypothesis is mu=18.5 versus mu not equal to 18.5 using alpha=0.001. The sample statistics are n=28, xbar=18.94, sigma=3.595.

- ○ z0=0.6476
- ○ z0=0.9533
- ○ z0=3.427
- ○ z0=-0.6476

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$$z_0 = \frac{\bar{x} - \mu_0}{\sigma / \sqrt{n}} = \frac{18.94 - 18.5}{3.595 / \sqrt{28}}$$

$$= 0.64764$$

Chapter 9, Case 1 2-sided

Monday, April 21, 2025   8:33 AM

QUESTION 3

Construct the rejection region for a test of hypothesis for the mean of single sample with variance known. The null hypothesis is mu=18.5 versus mu not equal to 18.5 using alpha=0.001. The sample statistics are n=19, xbar=19.99, sigma=3.324.

- ○ Reject H0 if |z0|>3.09
- ○ Reject H0 if |z0|>3.291
- ○ Reject Ho if z0>3.09
- ○ Reject Ho if z0>3.291
- ○ Reject Ho if Z0<-3.291
- ○ Reject Ho if Z0<-3.09

$H_1: \mu \neq 18.5 \rightarrow$ Reject Ho if

$$|z_0| > Z_{\alpha/2} = Z_{.001/2} = Z_{.0005}$$

$$|z_0| \geq 3.291$$

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Chapter 9, Case 1 2-sided

Monday, April 21, 2025   8:37 AM

QUESTION 5

Which is the correct conclusion for a test of hypothesis for the mean of single sample with variance known. The null hypothesis is mu=18.5 versus mu not equal to 18.5 using alpha=0.005. The sample statistics are n=29, xbar=18.36, sigma=4.851. The value of Z0 is -0.1554 and the rejection region is reject H0 if |z0|>2.807

○ Fail to reject H0

○ Reject H0

$Z_0 = -.1554$ reject H_0 if $|Z_0| > 2.807$

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is $|-.1554| > 2.807$
? No → fail to reject H_0
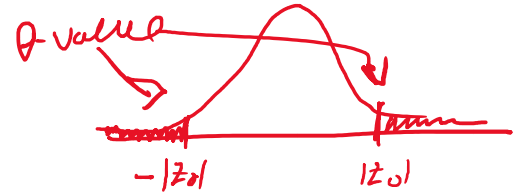
QUESTION 7

Find the p-value for a test of hypothesis for the mean of single sample with variance known. The null hypothesis is mu=132.3 versus mu not equal to 132.3 using alpha=0.05. The sample statistics are n=19, xbar=136.01, sigma=16.636 and the value of the test statistic, Z0, is 0.9721.

○ p-value=0.332046

○ p-value=0.833977

○ p-value=0.166023

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for $H_1: \mu \neq 132.3$

$$P\text{-value} = 2\left[1 - \Phi\left(|Z_0|\right)\right]$$
$$= 2\left[1 - \Phi(1.971)\right]$$
$$= 2(1 - .833977)$$
$$= .33205$$

Chapter 9, Case 1 2-sided

QUESTION 9

Using the p-value from a test of hypothesis for the mean of single sample with variance known, determine the correct conclusion for the hypothesis test. The null hypothesis is mu=25.8 versus mu not equal to 25.8 using alpha=0.005. The sample statistics are n=19, xbar=30.86, sigma=6.713. The results of hypothesis test include z0= 3.2856 and p-value=0.001018.

○ Reject H0

○ Fail to reject H0

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$\alpha = .005$

$P\text{-value} = .001$

if p-value $< \alpha$, Reject H0

is $.001 < .005$

? Yes, Reject Ho

Chapter 9, Case 1 lower

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QUESTION 1

→ z_0

Calculate the <mark>test statistic for a</mark> test of hypothesis for the mean of single sample with variance known. The null hypothesis is mu=25.8 versus mu less than 25.8 using alpha=0.01. The sample statistics are n=17, xbar=29.37, sigma=6.853.

- ○ z0=8.856
- ○ z0=-2.1479
- ○ z0=2.1479
- ○ z0=1.2923

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μ_0
↓

$H_0: \mu = 25.8$
$H_1: \mu < 25.8$

$$Z_0 = \frac{\bar{x} - \mu_0}{\sigma/\sqrt{n}} = \frac{29.37 - 25.8}{6.853/\sqrt{17}}$$

$$= 2.14789$$

Chapter 9, Case 1 Lower

Monday, April 21, 2025   8:51 AM

QUESTION 3

Construct the rejection region for a test of hypothesis for the mean of single sample with variance known. The null hypothesis is mu=25.8 versus mu less than 25.8 using alpha=0.1. The sample statistics are n=28, xbar=23.76, sigma=6.296.

- ○ Reject H0 if z0>1.282
- ○ Reject H0 if z0<-1.282
- ○ Reject Ho if |z0|>1.645
- ○ Reject Ho if Z0<-1.645

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for $\mu < \mu_0$, reject Ho if $z_0 < -z_\alpha = -z_{.1}$

$= -1.282$

Reject Ho if $z_0 < -1.282$

Chapter 9, Case 1 Lower

QUESTION 5

Which is the correct conclusion for a test of hypothesis for the mean of single sample with variance known. The null hypothesis is mu=32.0 versus mu less than 32.0 using alpha=0.05. The sample statistics are n=10, xbar=31.29, sigma=2.72. The value of Z0 is -0.8254 and the rejection region is reject HO if z0<-1.645

○ Fail to reject H0

○ Reject H0

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$$Z_0 = -0.8254$$

&

Reject Ho if $Z_0 < -1.645$

is $-.8254 < -1.645$

? No → fail to Reject Ho

Chapter 9, Case 1 Lower

QUESTION 7

Find the p-value for a test of hypothesis for the mean of single sample with variance known. The null hypothesis is mu=18.5 versus mu less than 18.5 using alpha=0.005. The sample statistics are n=28, xbar=17.63, sigma=4.618 and the value of the test statistic, Z0, is -0.9969.

○ p-value=0.841345
○ p-value=0.158655
○ p-value=0.317311

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p-value for $H_1 : \mu < \mu_0$ is

$$p\text{-value} = \Phi(z_0)$$
$$= \Phi(-.997) = \Phi(-1.00)$$
$$= .158655$$

Chapter 9, Case 1 Lower

Monday, April 21, 2025   8:59 AM

QUESTION 9

Using the p-value from a test of hypothesis for the mean of single sample with variance known, determine the correct conclusion for the hypothesis test. The null hypothesis is mu=0.5 versus mu less than 0.5 using alpha=0.1. The sample statistics are n=10, xbar=0.46, sigma=0.057. The results of hypothesis test include z0= -2.2191 and p-value=0.01324.

○ Reject H0

○ Fail to reject H0

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need α & p-value

$\alpha = .1$, p-value $= .01324$

Rule: if p-value $< \alpha$, Reject H_0

IS $.01324 < .01$? Yes → Reject H_0

~~Reject~~ Attendance

1-D

Chapter 9, Case 2 2-sided

Wednesday, April 23, 2025   8:48 AM

QUESTION 1

Calculate the test statistic for a test of hypothesis for the mean of single sample with variance unknown. The null hypothesis is mu=12.0 versus mu not equal to 12.0 using alpha=0.2. The sample statistics are n=18, xbar=12.51, S=2.177.

- ○ t0=1.937
- ○ t0=-0.9939
- ○ t0=0.9939
- ○ t0=4.2168

$$t_0 = \frac{\bar{x} - \mu_0}{S/\sqrt{n}} = \frac{12.51 - 12}{2.177/\sqrt{18}} = 0.99391$$

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Chapter 9, Case 2 2-sided

Wednesday, April 23, 2025   8:50 AM

QUESTION 3

Construct the rejection region for a test of hypothesis for the mean of single sample with variance unknown. The null hypothesis is mu=132.3 versus mu not equal to 132.3 using alpha=0.05. The sample statistics are n=7, xbar=144.04, S=18.877.

- ○ Reject Ho if t0>1.943
- ○ Reject Ho if t0>2.447
- ○ Reject H0 if |t0|>1.943
- ○ Reject Ho if t0<-2.447
- ○ Reject Ho if t0<-1.943
- ○ Reject H0 if |t0|>2.447

$\alpha = .05, \ n = 7$

Reject H_0 if $|t_0| > t_{\alpha/2, n-1} = t_{.025, 6}$
$= 2.447$

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Chapter 9, Case 2 2-sided

Wednesday, April 23, 2025   8:52 AM
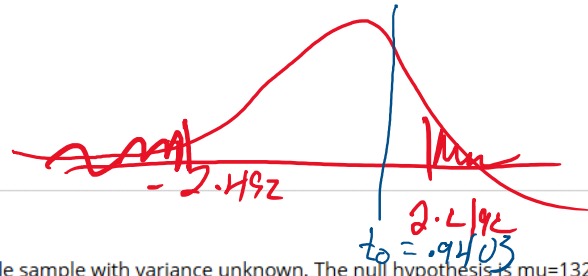
QUESTION 5

Which is the correct conclusion for a test of hypothesis for the mean of single sample with variance unknown. The null hypothesis is mu=132.3 versus mu not equal to 132.3 using alpha=0.02. The sample statistics are n=25, xbar=136.13, S=20.366. The value of t0 is 0.9403 and the rejection region is reject HO if |t0|>2.492

- ○ Fail to reject H0
- ○ Reject H0

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(handwritten notes)

-2.492 2.492

$t_0 = .9403$

① $t_0 = .9403$

② Reject H if $|t_0| > 2.492$

is $|.9403| > 2.492$? no, fail to reject H0

Chapter 9, Case 2 2-sided

Wednesday, April 23, 2025   8:54 AM

QUESTION 7

Using the p-value from a test of hypothesis for the mean of single sample with variance unknown, determine the correct conclusion for the hypothesis test. The null hypothesis is mu=132.3 versus mu not equal to 132.3 using alpha=0.1. The sample statistics are n=5, xbar=134.52, S=11.084. The results of hypothesis test include t0= 0.4479 and p-value=0.677413.

○ Fail to reject H0

○ Reject H0

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p-value = .6774

α = .1

Rule : if p-value < α, reject H0

is .06774 < .1 ? no → fail to reject H0

Chapter 9, Case 2 Lower

Wednesday, April 23, 2025   8:56 AM
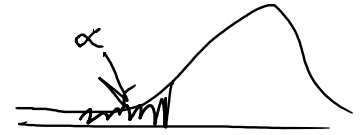
QUESTION 1

Calculate the test statistic for a test of hypothesis for the mean of single sample with variance unknown. The null hypothesis is mu=0.5 versus mu less than 0.5 using alpha=0.0025. The sample statistics are n=19, xbar=0.51, S=0.053.

- ○ t0=-0.8224
- ○ t0=0.8224
- ○ t0=3.5849
- ○ t0=67.6397

$$t_0 = \frac{\bar{x} - \mu_0}{S/\sqrt{n}} = \frac{.51 - .5}{.053/\sqrt{19}} = 0.82243$$

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$H_0: \mu = 12$

$H_1: \mu \leq 12$

QUESTION 3

Construct the rejection region for a test of hypothesis for the mean of single sample with variance unknown. The null hypothesis is mu=12.0 versus mu less than 12.0 using alpha=0.025. The sample statistics are n=18, xbar=11.57, S=2.025.

- ○ Reject Ho if |t0|>2.458
- ○ Reject H0 if t0<-2.11
- ○ Reject Ho if t0<-2.458
- ○ Reject Ho if t0>2.11
- ○ Reject H0 if |t0|>2.11

Reject H_0 if $t_0 < -t_{\alpha, n-1}$

$= -t_{.025, 17}$

$= -2.110$

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Chapter 9, Case 2 Upper

Wednesday, April 23, 2025   9:03 AM

QUESTION 1

Calculate the test statistic for a test of hypothesis for the mean of single sample with variance unknown. The null hypothesis is mu=18.5 versus mu greater than 18.5 using alpha=0.005. The sample statistics are n=10, xbar=17.04, S=5.036.

- ○ t0=-2.8991
- ○ t0=-0.9168
- ○ t0=0.9168
- ○ t0=-0.5757

$$t_0 = \frac{\overline{x} - \mu_0}{S/\sqrt{n}} = \frac{17.04 - 18.5}{5.036/\sqrt{10}} = -.91678$$

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Chapter 9, Case 2 Upper

QUESTION 3

Construct the rejection region for a test of hypothesis for the mean of single sample with variance unknown. The null hypothesis is mu=12.0 versus mu greater than 12.0 using alpha=0.005. The sample statistics are n=2, xbar=13.62, S=1.953.

- Reject H0 if t0>63.657
- Reject Ho if |t0|>127.321
- Reject H0 if |t0|>63.657
- Reject Ho if t0<-127.321
- Reject Ho if t0<-63.657

Reject Ho if $t_0 > t_{\alpha, n-1} = t_{.005, 1} = 63.657$

Attendance: 1-C

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Chapter 9, Case 3 2-sided

Monday, April 28, 2025   8:20 AM

QUESTION 1

Calculate the test statistic for a test of hypothesis for the variance of normal distribution. The null hypothesis is sigma^2=324.0 versus sigma^2 not equal to 324.0 using alpha=0.2. The sample statistics are n=28, xbar=126.28, S=50.933.

○ ChiSquared0=76.3995
○ ChiSquared0=216.1809
○ ChiSquared0=3.3722
○ ChiSquared0=9.5419

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$$\chi_0^2 = \frac{(n-1)S^2}{\sigma_0^2}$$

$$= \frac{(28-1)(50.933)^2}{324.0}$$

$$= 216.181$$

$$\sigma_0^2 = 324$$
$$n = 28$$
$$S = 50.933$$

Chapter 9, Case 3 2-sided

Monday, April 28, 2025   8:25 AM

$n = 29$

$\alpha = .01$

QUESTION 3

Construct the rejection region for a test of hypothesis for the variance of normal distribution. The null hypothesis is sigma^2=17.64 versus sigma^2 not equal to 17.64 using alpha=0.01. The sample statistics are n=29, xbar=17.28, S=9.817.

- ○ Reject Ho if chiSquare0<13.56
- ✓ Reject H0 if ChiSquare0<12.46 or ChiSquare0>50.99
- ○ Reject Ho if chiSquare0>48.28
- ○ Reject Ho if ChiSquare0>50.99
- ○ Reject H0 if ChiSquare0<13.56 or ChiSquare0>48.28
- ○ Reject Ho if chiSquare0<12.46

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Reject H₀ if

$$\chi_0^2 > \chi_{\alpha/2, n-1}^2 = \chi_{.005, 28}^2 = 50.99$$

or

$$\chi_0^2 < \chi_{1-\alpha/2, n-1}^2 = \chi_{.995, 28}^2 = 12.46$$

Chapter 9, Case 3 2-sided

QUESTION 5

What is the correct conclusion for a test of hypothesis for the variance of a normal distribution. The null hypothesis is Sigma^2=44.89 versus sigma^2 not equal to 44.89 using alpha=0.2. The sample statistics are n=91, xbar=22.64, S=18.005. The value of ChiSquare0 is 649.9488 and the rejection region is reject HO if ChiSquare0<73.29 or ChiSquare0>107.57

○ Fail to reject H0

○ Reject H0

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① $\chi_0^2 = 649.9488$

② Reject Ho if

$\chi_0^2 < 73.29 \longrightarrow$ no

or

$\chi_0^2 > 107.57 \longrightarrow$ yes

Reject Ho

Chapter 9, Case 3 Lower

Monday, April 28, 2025   8:35 AM

QUESTION 1

Calculate the test statistic for a test of hypothesis for the variance of normal distribution. The null hypothesis is sigma^2=4.41 versus sigma^2 less than 4.41 using alpha=0.05. The sample statistics are n=10, xbar=12.11, S=0.815.

- ○ ChiSquared0=23.1902
- ✓ ChiSquared0=1.3556
- ○ ChiSquared0=59.7538
- ○ ChiSquared0=3.4929

$$\chi_0^2 = \frac{(n-1)S^2}{\sigma_0^2}$$

$$= \frac{(10-1)(.815)^2}{4.41}$$

$$= 1.35556$$

$n = 10$

$S = .815$

$\sigma_0^2 = 4.41$

Chapter 9, Case 3 Lower

QUESTION 3 $tied\ to\ H_1: \sigma^2 < 324$

Construct the rejection region for a test of hypothesis for the variance of normal distribution. The null hypothesis is sigma^2=324.0 versus sigma^2 less than 324.0 using alpha=0.05. The sample statistics are n=5, xbar=130.0, S=14.414.

○ Reject Ho if ChiSquare0>11.14

○ Reject Ho if chiSquare0>9.49

○ Reject H0 if ChiSquare0<0.48 or ChiSquare0>11.14

○ Reject H0 if ChiSquare0>0.71 or ChiSquare0>9.49

○ Reject Ho if chiSquare0<0.48

○ Reject Ho if chiSquare0<0.71

Reject Ho if $\chi_0^2 < \chi_{1-\alpha, n-1}^2$

$\alpha = .05$

$\chi_{1-.05, 5-1}^2 = \chi_{.95, 4}^2 = .71$

Reject Ho if $\chi_0^2 < .71$

Chapter 9, Case 3 Upper

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$$H_0 : \sigma^2 = 324$$
$$H_1 : \sigma^2 > 324$$

QUESTION 1

Calculate the test statistic for a test of hypothesis for the variance of normal distribution. The null hypothesis is sigma^2=324.0 versus sigma^2 greater than 324.0 using alpha=0.05. The sample statistics are n=13, xbar=136.87, S=47.249.

- ○ ChiSquared0=4.5715
- ○ ChiSquared0=1.7416
- ○ ChiSquared0=82.684
- ○ ChiSquared0=31.4993

$$\chi^2_0 = \frac{(n-1)s^2}{\sigma^2_0} = \frac{(13-1)(47.249)^2}{324}$$

$$= 82.684$$

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Chapter 9, Case 3 Upper

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$H_1 : \sigma^2 > 11.56$

QUESTION 3

Construct the rejection region for a test of hypothesis for the variance of normal distribution. The null hypothesis is sigma^2=11.56 versus sigma^2 greater than 11.56 using alpha=0.01. The sample statistics are n=2, xbar=30.76, S=4.321.

- ○ Reject H0 if ChiSquare0<0.0 or ChiSquare0>7.88
- ○ Reject Ho if chiSquare0<0.0
- ○ Reject Ho if chiSquare0<0.0
- ☑ Reject Ho if chiSquare0>6.63
- ○ Reject Ho if ChiSquare0>7.88
- ○ Reject H0 if ChiSquare0<0.0 or ChiSquare0>6.63

Reject Ho if $\chi_0^2 > \chi_{\alpha, n-1}^2 = \chi_{.01, 2-1}^2$

$\chi_0^2 > 6.63$

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