Chapter 9 – Hypothesis Testing

Methods for Drawing Inferences

- We can draw inferences on a population parameter in two ways:
  - Estimation (Chapter 8)
  - Hypothesis Testing (Chapter 9)

Hypothesis Testing

- Hypothesis testing is the process of making decisions about the value of a population parameter.

Establishing the Hypotheses

- *Null Hypothesis*: A hypothesis about a parameter that often denotes a theoretical value, a historical value, or a production specification.
  - Denoted as H_0
  - This is the statement that is under investigation or being tested. Usually the null hypothesis represents a statement of "no change", "no difference", or put another way, "things haven't changed"
- *Alternate Hypothesis*: A hypothesis that differs from the null hypothesis, such that if we reject the null hypothesis, we will accept the alternate hypothesis.
  - Denoted as H_1 (in other sources H_A).
  - This is the statement you will adopt in the situation where the evidence (data) is so strong that you reject H_o. A statistical test is designed to assess the strength of evidence (data) against the null hypothesis.

Motivational Example –

The Survey of Study Habits and Attitudes (SSHA) is a psychological test that measures students' study habits and attitude toward school. Scores range from 0 to 200. The mean score for U.S. college students is about 115. A teacher suspects that older students have better attitudes toward school. She gives the SSHA to a group of 35 students who are at least 30 years old. The sample results are $\bar{x}$ = 125.7 and s = 30.1. Is this good evidence that older students, on average, have better study habits and attitudes toward school than the typical college student?

Here the question is do older students do better on the SSHA score than average students? We perform hypothesis test to answer this question.

THE MAIN CONCEPTS OF HYPOTHESIS TESTING

A statistical test begins by supposing for the sake of argument that the effect we seek is not present. We then look for evidence against this supposition and in favor of the effect we hope to find.

• For the null hypothesis, Ho, state a claim that we will try to find evidence against. The null hypothesis is often a statement of "no effect" or "no difference". Nothing special has occurred, no change has taken place -- the "status quo" hypothesis.

• The statement we hope or suspect is true instead of Ho is the alternative hypothesis, Ha. A significance test looks for evidence against the null hypothesis and in favor of the alternative hypothesis. The evidence is strong if the outcome we observe would rarely come up when the null hypothesis is true.

That is, if the sample results can easily occur when Ho is true, we attribute the relatively small discrepancy between the null hypothesis and the sample results to chance. If the sample results cannot easily occur when Ho is true, we explain the relatively large discrepancy between the null hypothesis and the sample results by concluding that Ho is not true (and so we conclude that Ha is true).

Hints:
(1) The null hypothesis (H_o) will always contain equality.
(2) It's often easier to write down the alternative hypothesis (H_a) first.
(3) P-value helps us assess the amount of evidence the sample provides against Ho and in favor of Ha. P-value tells us how unlikely the sample results are when Ho is true. Very small p-values mean the sample results are very unlikely to occur when Ho is true and therefore the evidence against Ho is strong.
"The p-value is the probability that sample results like those obtained or more extreme than those obtained occur when H_o is true"
(4) Language: Based on the p-value, we either "reject Ho in favor of H_a" or we "fail to reject H_o."
(Sometimes I say "retain H_o" instead of "fail to reject H_o.)

Guidelines for p-value

P-value is defined as the probability of obtaining sample results as extreme (or more extreme) as those actually obtained, if Ho were true. ("Extreme" means far from what we would expect if Ho were true. The alternative hypothesis determines which directions count against Ho.)

For example, p-value = .02 means sample results like those obtained or more extreme than those obtained only occur 2% of the time when H_o is true.

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P-value tells us how unlikely the sample results are when Ho is true. Very small p-values mean the sample results are very unlikely to occur when Ho is true and therefore the evidence against Ho is strong.

The smaller the p-value, the stronger is the evidence against Ho. The following can be used as guidelines when a significance level is not preset. They should not be viewed as p-value “cutoffs.”

p-value > .1 ***insufficient evidence*** against Ho
.05 < p-value ≤ .10 ***some evidence*** against Ho
.01 < p-value ≤ .05 ***fairly strong evidence*** against Ho
.001 < p-value ≤ .01 ***strong evidence*** against Ho
p-value ≤ .001 ***very strong evidence*** against Ho

Reporting a test of significance
1. Give the null and alternative hypotheses. Define the parameters involved in the study.
2. Summarize the sample data for your readers.
3. Give the test statistic and its distribution, the observed test statistic, and the p-value.
4. Use the p-value to draw a conclusion – reject the null hypothesis in favor of the alternative or retain the null hypothesis. State your conclusion in context of the problem.

Statistical Hypotheses

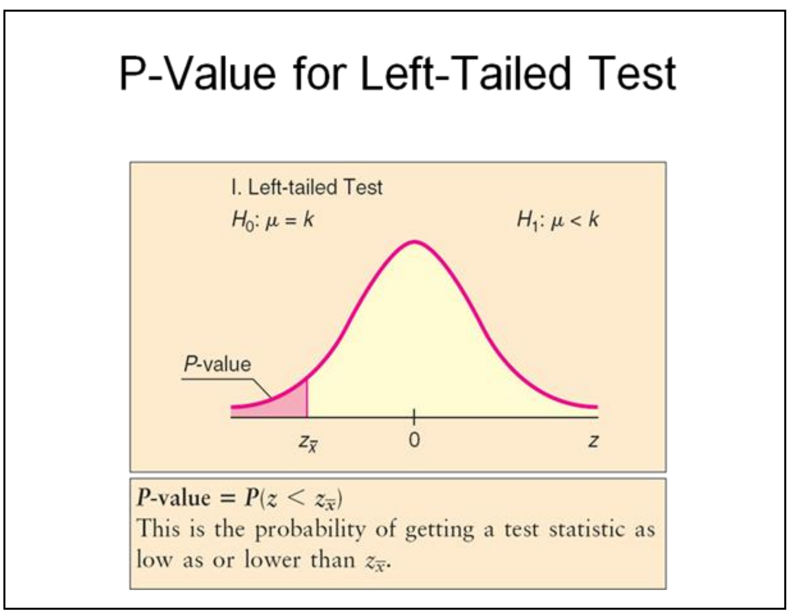
- The null hypothesis is always a statement of equality.
  - H_0: $\mu = k$, where k is a specified value
- The alternate hypothesis states that the parameter (μ or p) is less than, greater than, or not equal to a specified value.

Example - Which of the following is an acceptable null hypothesis?

a). H_0: $\mu \le 1.2$ b). H_0: $\mu > 1.2$
c). H_0: $\mu = 1.2$ d). H_0: $\mu \ne 1.2$

Types of Tests

- Left-Tailed Tests: H_1: $\mu < k$
  H_1: $p < k$

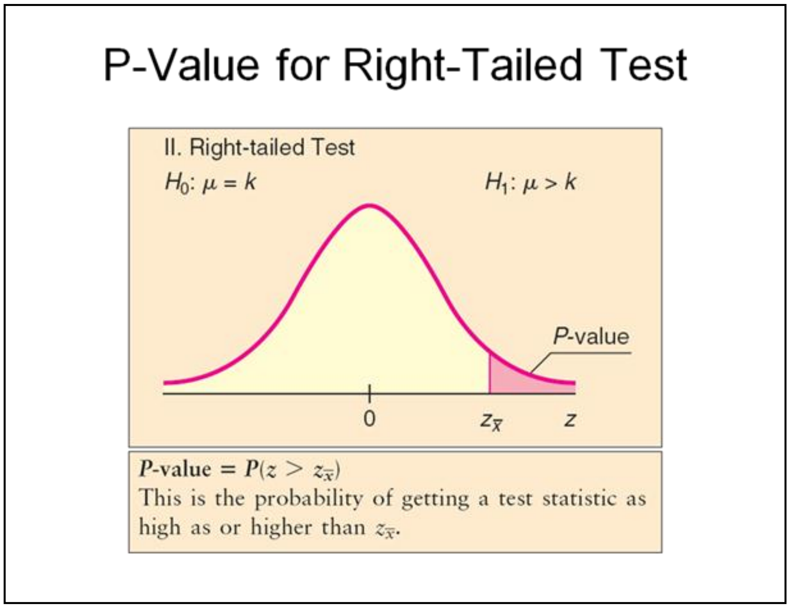


If the alternative hypothesis states that the parameter is less than the value claimed in the null hypothesis.

Note:

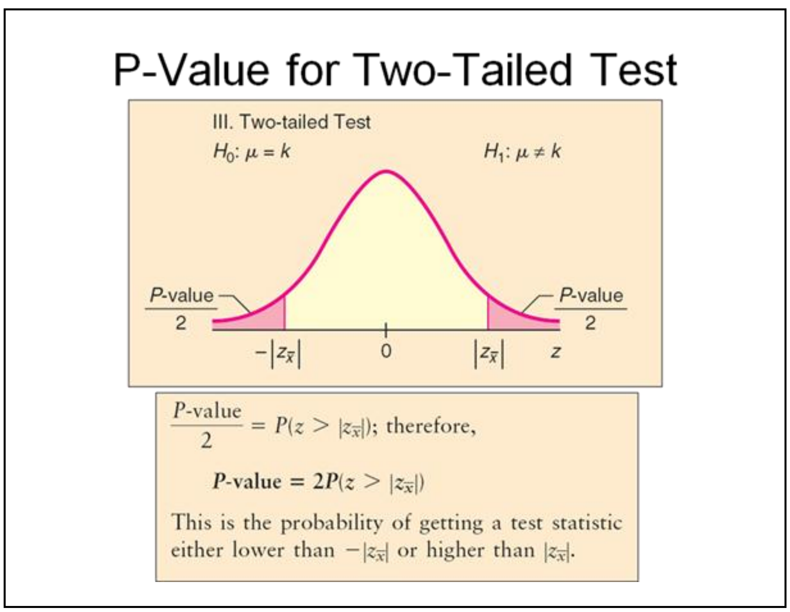
$$z_{\bar{x}} = \frac{\bar{x}-\mu}{\frac{\sigma}{\sqrt{n}}}$$

- Right-Tailed Tests: $H_1: \mu > k$
  $H_1: p > k$



If the alternative hypothesis states that the parameter is greater than the value claimed in the null hypothesis.

- Two-Tailed Tests: $H_1: \mu \neq k$
  $H_1: p \neq k$



If the alternative hypothesis states that the parameter is different from (or not equal to) the value claimed in the null hypothesis.

For when σ is unknown use s

H_o: *poplation parameter = hypothesized value* $\quad p-value = 2P(t \geq |t_{obs}|)$
H_a: *poplation parameter ≠ hypothesized value*

H_o: *poplation parameter = hypothesized value* $\quad p-value = P(t \geq t_{obs})$
H_a: *poplation parameter > hypothesized value*

H_o: *poplation parameter = hypothesized value* $\quad p-value = P(t \leq t_{obs})$
H_a: *poplation parameter < hypothesized value*

Test Statistic: $t_{obs} = \frac{\bar{x}-\mu}{\frac{s}{\sqrt{n}}}$~t(n-1)

For when σ is known

H_o: *poplation parameter = hypothesized value* $\quad p-value = 2P(z \geq |z_{obs}|)$
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H_o: *poplation parameter = hypothesized value* $\quad p-value = P(z \geq z_{obs})$
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H_o: *poplation parameter = hypothesized value* $\quad p-value = P(z \leq z_{obs})$
H_a: *poplation parameter < hypothesized value*

Test Statistic: $z_{obs} = \frac{\bar{x}-\mu}{\frac{\sigma}{\sqrt{n}}}$~N(0,1)

Example - A production manager believes that a particular machine averages 150 or more parts produced per day. What would be the appropriate hypotheses for testing this claim?

a). H_0: $\mu \leq 150$; H_1: $\mu > 150$ b). H_0: $\mu > 150$; H_1: $\mu = 150$
c). H_0: $\mu = 150$; H_1: $\mu \neq 150$ d). H_0: $\mu = 150$; H_1: $\mu > 150$

Hypothesis Testing Procedure
1) Select appropriate hypotheses.
2) Draw a random sample.
3) Calculate the test statistic.
4) Assess the compatibility of the test statistic with H_0.
5) Make a conclusion in the context of the problem.

Hypothesis Test of μ: x is Normal, σ is unknown

1) State the null hypothesis, alternate hypothesis, and level of significance.
2) If x is normally distributed (or mound-shaped), any sample size will suffice. If not, $n \geq 30$ is required.

$$\text{Calculate: } t_{obs} = \frac{\bar{x}-\mu}{\frac{s}{\sqrt{n}}} \ with\ df = n-1$$

3) Use the Student's *t* table and the type of test (one or two-tailed) to determine (or estimate) the *P*-value.
4) Make a statistical conclusion:

   If *P*-value $\leq \alpha$, reject H_0 in favor of the alternative

   If *P*-value $> \alpha$, do not reject H_0 "retain H_o"
5) Make a context-specific conclusion.

Hypothesis Test of μ: x is Normal, σ is known

1) State the null hypothesis, alternate hypothesis, and level of significance.
2) If *x* is normally distributed, any sample size will suffice. If not, $n \geq 30$ is required.

$$\text{Calculate: } z_{obs} = \frac{\bar{x}-\mu}{\frac{\sigma}{\sqrt{n}}} \sim N(0,1)$$

3) Use the standard normal table and the type of test (one or two-tailed) to determine the *P*-value.
4) Make a statistical conclusion:

   If *P*-value $\leq \alpha$, reject H_0 in favor of the alternative

   If *P*-value $> \alpha$, do not reject H_0 "retain H_o"
5) Make a context-specific conclusion.

Types of Errors in Statistical Testing

- Since we are making decisions with incomplete information (sample data), we can make the wrong conclusion.
  - *Type I Error:* Re**j**ecting the null hypothesis when the null hypothesis is true. (j comes before t) – Worse Case
  - *Type II Error:* Re**t**ain the null hypothesis when the null hypothesis is false. (t comes after j) - Conservative

Errors in Statistical Testing

- Unfortunately, we usually will not know when we have made an error.
- We can only talk about the *probability* of making an error.
- *Decreasing* the probability of making a type I error will *increase* the probability of making a type II error (and vice versa).
- We can only decrease the probability of both types of errors by increasing the sample size (obtaining more information), but this may not be feasible in practice.

The Probabilities Associated with Testing

	Our Decision	
Truth of H_o	***And if we retain H_o***	***And if we Reject H_o***
H_o is TRUE	Correct Decision; no error	TYPE I ERROR
	Probability = 1-α	Probability = α
		"α is called the level of significance of the test"
H_o is FALSE	TYPE II ERROR	Correct Decision; no error
	Probability = β	Probability = 1-β
		"1-β is called the power of the test"

Level of Significance

- Good practice requires us to specify in advance the risk level of type I error we are willing to accept.
- The **probability of type I error is the level of significance for the test, denoted by *α* (alpha).** Example – α=0.01 In order to reject H_o we need a p-value ≤α. Meaning that we are not willing to take more than a 1% chance of rejecting H_o when it is actually true.

Type II Error

- The probability of making a type II error is denoted by *β* (Beta). The value of *β* is chosen just like the value of α is chosen, or these will be given to you in the context of the problem.
- *1 – β* is called the power of the test.
  1 – β is the probability of rejecting H_0 when H_0 is false (a correct decision).
- Researchers also face the risk of failing to detect an effect or difference that is really there. That is the effect described in the Ha really is present, but our sample results didn't unveil it.
  When we retain Ho it means the data we have on hand doesn't detect the difference we hoped to see, so when we retain Ho we may want to investigate the probability of a Type II Error.
  If the probability of Type II Error is low then we will conclude that the difference we had hoped to see really isn't there.
  If the probability of Type II Error is not low then we may conclude that the sample results possibly just were not able to unveil a difference

Power = 1 – P(Type II Error) = 1 - β

Power is our ability to detect an "effect" (difference) when one exists.

The power of a statistical test increases as the level of significance, α increases.

Using a larger value of α will increase our power but it will also increase the probability of a type I error.

Items that affect Power:

1. Size of the effect
2. Preset significance level (α)
3. Variability of the population
4. Sample Size from which we sample

Type I Error: REJECTED H_o when H_o is TRUE
Type II Error: RETAINED H_o when H_o is FALSE

Definition – Size of the effect – the distance between the Ho value and the truth is called the effect size.

It is easier to detect a large effect, when the effect is small, it is easier to make a Type II Error and retain Ho (no difference) when there truly is a difference

Example - For a particular experiment, *P-value* = 0.17 and α = 0.05. What is the appropriate conclusion?

a). Reject the null hypothesis.
b). Do not reject the null hypothesis.
c). Reject both the null hypothesis and the alternative hypothesis.
d). Accept both the null hypothesis and the alternative hypothesis.

Interpretation of Testing Terms

Term	Meaning
Fail to reject H_0	There is not enough evidence in the data (and the test being used) to justify a rejection of H_0. This means that we retain H_0 with the understanding that we have not proved it to be true beyond all doubt.
Reject H_0	There is enough evidence in the data (and the test employed) to justify rejection of H_0. This means that we choose the alternate hypothesis H_1 with the understanding that we have not proved H_1 to be true beyond all doubt.

Basic Components of a statistical Test

A statistical test can be thought of as a package of five basic ingredients.
1. Null Hypothesis Ho, Alternative Hypothesis Ha, and preset level of significance α.
2. Test Statistic and sampling distribution
   These are mathematical tools used to measure compatibility of sample data and the null hypothesis.
3. P-value
   This is the probability of obtaining a test statistic from the sampling distribution that is as extreme (or more extreme) as those actually obtained, if Ho were true.
4. Test Conclusion
   Retain Ho or Reject Ho
5. Interpretation of the test results
   Give a simple explanation of your conclusions in the context of the application.

Example - Suppose that the test statistic *z* = 1.85 for a right-tailed test. Use Table 3 in the Appendix to find the corresponding *P*-value. ***Calculator: normalcdf(1.85, $_E$99)***

Using Table 4 to Estimate *P*-values

Suppose we calculate *t = 2.22* for a one-tailed test from a sample size of 6. *df = n – 1 = 5.*

TABLE 4 Critical Values for Student's *t* Distribution

one-tail area	0.250	0.125	0.100	0.075	0.050	0.025	0.010	0.005	0.0005
two-tail area	0.500	0.250	0.200	0.150	0.100	0.050	0.020	0.010	0.0010
d.f. \ *c*	0.500	0.750	0.800	0.850	0.900	0.950	0.980	0.990	0.999
1	1.000	2.414	3.078	4.165	6.314	12.706	31.821	63.657	636.619
2	0.816	1.604	1.886	2.282	2.920	4.303	6.965	9.925	31.599
3	0.765	1.423	1.638	1.924	2.353	3.182	4.541	5.841	12.924
4	0.741	1.344	1.533	1.778	2.132	2.776	3.747	4.604	8.610
5	0.727	1.301	1.476	1.699	2.015	2.571	3.365	4.032	6.869
6	0.718	1.273	1.440	1.650	1.943	2.447	3.143	3.707	5.959

$0.025 < P\text{-value} < 0.050$

Testing a Proportion p

Binomial Experiments:

r (# of successes) is a binomial variable
n is the number of independent trials
p is the probability of success on each trial

Test Assumption: $np > 5$ and $n(1 - p) > 5$

Types of Proportion Tests

Left-Tailed Test	Right-Tailed Test	Two-Tailed Test
$H_0\colon p = k$	$H_0\colon p = k$	$H_0\colon p = k$
$H_1\colon p < k$	$H_1\colon p > k$	$H_1\colon p \neq k$

The Distribution of the Sample Proportion

Recall the distribution of $\hat{p} = \frac{r}{n}$ is approximately normal with:

$$\mu = p \quad \text{and} \quad \sigma = \sqrt{\frac{p(1-p)}{n}}$$

Converting the Sample Proportion to z

$$z = \frac{\hat{p} - p}{\sqrt{\frac{pq}{n}}}$$

Where $\hat{p} = \frac{r}{n}$ is the sample test statistic

n = number of trials

p = proportion specified in Ho

q = 1- p

Testing *p*

1) *State the null hypothesis, alternate hypothesis, and level of significance.*
2) *Check $np > 5$ and $nq > 5$*

   (recall $q = 1 - p$). Compute: $Z = \frac{\bar{p} - p}{\sqrt{\frac{pq}{n}}}$ p = the specified value in H_0

3) Use the standard normal table and the type of test (one or two-tailed) to determine the *P*-value.
4) Make a statistical conclusion:

   If *P*-value ≤ α, reject H_0 in favor of H_a

   If *P*-value > α, do not reject H_0 "retain H_o"
5) Make a context-specific conclusion.

Critical Thinking: Issues Related to Hypothesis Testing

- *Central question – Is the value of test statistic too different from zero for the difference to be due to chance alone?*
- *The P-value gives the probability that the test statistic's value is due to chance alone.*
- *If the P-value is close to α, then we might attempt to clarify the results by*
  - *- increasing the sample size*
  - *- controlling the experiment to reduce the standard deviation*
- *How reliable is the study and the measurements in the sample? – Consider the source of the data and the reliability of the organization doing the study.*

	How to Calculator	
	σ is unknown	***σ is known***
Test Statistic Equation	$t_{obs} = \frac{\bar{x}-\mu}{\frac{s}{\sqrt{n}}}$ *with df n-1*	$z_{obs} = \frac{\bar{x}-\mu}{\frac{\sigma}{\sqrt{n}}} \sim N(0,1)$
P-value Equations	*Located on Page 5 of Chapter 9*	*Located on Page 5 of Chapter 9*
Calculator for Test Statistic and P-value	*Stat → Test → T test*	*Stat → Test → Z test*
Confidence Interval	*Stat → Test → T interval*	*Stat → Test → Z interval*

	How to Calculator – Binomial Proportion
Test Statistic Equation	$z = \frac{\hat{p}-p}{\sqrt{\frac{pq}{n}}} \sim N(0,1)$
P-value Equations	*Located on page 5 of Chapter 9*
Calculator for Test Statistic and P-value	*Stat → Test → 1 Prop Z Test*
Confidence Interval	*Stat → Test → 1 Prop Z Interval*

When you are given data for a problem use the same methods listed above just choose Data instead of Stat on your Calculator.

Example - A fire insurance company felt that the mean distance from a home to the nearest fire department in a suburb of Chicago was at least 4.7 miles. It set its fire insurance rates accordingly. Members of the community set out to show that the mean distance was less than 4.7 miles. This, they felt, would convince the insurance company to lower its rates. They randomly identified 64 homes and measured the distance to the nearest fire department for each. The resulting sample mean was 4.4 miles and the sample standard deviation was 2.4 miles. Does the sample show sufficient evidence to support the community's claim? If yes, estimate the average distance from homes to the nearest fire department. Use $\alpha = 0.05$

Do you have s or σ or p?

Are you going to use Z_{obs} or t_{obs}?

Step 1: Write down what you know

Step2: Hypothesis Testing; give H_o, H_a, alpha level, what type of tail is the test, define the population parameter

Step3: Test Statistic

Step 4: P-value

Step 5: Conclusion (Reject or Retain) and Interpret in lamens terms.

Step 6: **Only do this if you Rejected H_o**. Find a 100(1-α)% Confidence Interval and interpret in lamens terms.

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Example - At Farmer's Dairy, a machine is set to fill 32-ounce milk cartons. Of course, the amount varies slightly from carton to carton but when the machine is working properly, the mean net weight of these cartons is 32 ounces. The quality control director at this dairy takes a sample of 35 such cartons each week to see if filling should be paused so the machine can be stopped and adjusted for overfilling or under filling. (Both are undesirable since under filling cheats the customers and overfilling costs the dairy money.) A recent sample of 35 cartons produced a mean net weight of 31.90 ounces and a standard deviation of .15 ounces. Based on this sample, would you conclude that the machine needs to be adjusted?
If you conclude that the machine needs to be adjusted, estimate the current fill weight for the machine so the quality control team can make the appropriate adjustments to get the machine in good working condition again. Use a 95% confidence interval and interpret your interval estimate. (For example, is the machine overfilling or under filling, and by how much?)

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Example – A team of eye surgeons has developed a new technique for a risky eye operation to restore the sight of people blinded from a certain disease. Under the old method, it is known that only 30% of the patients who undergo this operation recover their eyesight. Suppose that surgeons in various hospitals have preformed a total of 225 operations using the new method and that 88 have been successful (the patients fully recover their sight). Can we justify the claim that the new method is better than the old one? (Use $\alpha = 0.01$)

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Step 6: **Only do this if you Rejected H_o**. Find a 100(1-α)% Confidence Interval and interpret in lamens terms.

Example - How long does it take to have food delivered? A Chinese restaurant advertises that delivery will be no more than 30 minutes. A random sample of delivery times is shown below. Based on this sample, is the delivery time greater than 30 minutes? Use a 5% level of significance. Assume that the distribution of delivery times is normal.

32	28	21	39	30	27	29
39	32	28	42	25	26	30

Do you have s or σ or p?
Are you going to use Z_{obs} or t_{obs}?

Step 1: Write down what you know

Step2: Hypothesis Testing; give H_o, H_a, alpha level, what type of tail is the test, define the population parameter

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Step 5: Conclusion (Reject or Retain) and Interpret in lamens terms.

Step 6: **Only do this if you Rejected H_o.** Find a 100(1-α)% Confidence Interval and interpret in lamens terms.

Example - The owner of a comedy club has historically based her business decisions on the average age of her customers being 30 years. A random sample of customer ages is shown below. Based on this sample, is the average age greater than 30 years? Use a 5% level of significance. Assume that the distribution of ages is approximately normal.

37	30	26	35	45	42	51	40
43	27	39	38	46	21	28	20

Do you have s or σ or p?

Are you going to use Z_{obs} or t_{obs}?

Step 1: Write down what you know

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Example - A small electronics store has begun to advertise in the local newspaper. Before advertising, the long term mean weekly sales were \$9820. A random sample of 10 weeks while the newspaper ads were running had a sample mean weekly sale of $\bar{x}$ = \$10,960. Does this indicate that the population mean weekly sales is now more than \$9820? Test at the 5% level of significance. Assume σ = \$1580.

A. State the null and alternate hypotheses. **1. A.** ___________

(a) H_0: $\mu = 9820$; H_1: $\mu < 9820$ (b) H_0: $\mu = 9820$; H_1: $\mu > 9820$

(c) H_0: $\bar{x} = 10{,}960$; H_1: $\bar{x} > 10{,}960$ (d) H_0: $\mu = 10{,}960$; H_1: $\mu > 10{,}960$

(e) H_0: $\mu > 10{,}960$; H_1: $\mu = 10{,}960$

B. Compute the value of the test statistic. **B.** ___________

(a) $t = 2.28$ (b) $z = 2.28$

(c) $t = -2.28$ (d) $z = -2.28$ (e) $z = 0.72$

C. Find the *P*-value for the sample test statistic. **C.** ___________

(a) *P*-value = 0.024 (b) *P*-value = 0.011

(c) *P*-value = 0.976 (d) *P*-value = 0.989 (e) *P*-value = 0.236

D. Find the critical value. **D.** ___________

(a) $z_0 = 2.33$ (b) $z_0 = 1.96$

(c) $t_0 = -1.96$ (d) $z_0 = 1.645$ (e) $t_0 = -1.96$

E. Based on your answers for parts A–D, what is your conclusion? **E.** ___________

(a) Do not reject H_0 (b) Reject H_0 (c) Cannot determine

Example - Results from a previous study showed 79% of all high school seniors from a certain city plan to attend college after graduation. In a random sample of 200 high school seniors from this city, 162 planned to attend college. Does this indicate that the percentage has increased from that in the previous study? Test at 5% level of significance.

Do you have s or σ or p?
Are you going to use Z_{obs} or t_{obs}?

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