# Testing of Hypothesis

# Notations

## Population parameters

Population mean ($\mu$)
Population standard deviation ($\sigma$)
Population size ($N$)
Population proportion ($P$)

## Sample statistic

Sample mean ($\bar{x}$)
Sample standard deviation ($s$)
Sample size ($n$)
Sample proportion ($p$)

# Hypothesis Testing

## Statistical hypothesis

is a statement or a claim about one or more population parameters

An hypothesis to be tested or to answer a question - Alternative hypothesis ($H_1$ or $H_a$)
An hypothesis of no difference, opposes $H_1$ - Null hypothesis ($H_0$)

## Example

Suppose we test for population mean. Then
**Null Hypothesis** $H_0 : \mu = \mu_0$
**Alt Hypothesis** $H_1 : \mu \neq \mu_0$ **or** $\mu > \mu_0$ **or** $\mu < \mu_0$
If $\mu \neq \mu_0$, then the test is called **Two-tailed**.
If $\mu > \mu_0$, then it is called **Right tailed test**.
If $\mu < \mu_0$, then it is called **Left tailed test**.

# Types of errors

| | $H_0$ is true | $H_0$ is false |
|---|---|---|
| Reject $H_0$ | Type I error | Correct decision |
| Accept $H_0$ | Correct decision | Type II error |

P(Type I error) $= \alpha =$ level of significance (LOS)
P(Type II error) $= \beta$

# Steps involved in Hypothesis testing

- Formulate Null and Alternate hypothesis
- Identify the level of significance
- Test statistic
- Critical (or) Rejection region
- Conclusion

$$\begin{aligned} \text{If } n \geq 30 &\implies \text{Large sample} \\ \text{If } n < 30 &\implies \text{Small sample} \end{aligned}$$

# Table corresponding to critical values

| Test LOS | 1% (0.01) | 5% (0.05) | 10% (0.1) |
|---|---|---|---|
| Two tailed | $\lvert Z_{\frac{\alpha}{2}} \rvert = 2.58$ | $\lvert Z_{\frac{\alpha}{2}} \rvert = 1.96$ | $\lvert Z_{\frac{\alpha}{2}} \rvert = 1.645$ |
| Right tailed | $Z_\alpha = 2.33$ | $Z_\alpha = 1.645$ | $Z_\alpha = 1.28$ |
| Left tailed | $Z_\alpha = -2.33$ | $Z_\alpha = -1.645$ | $Z_\alpha = -1.28$ |

# Test for single proportion

## Conditions

- $nP \geq 5$ and $n(1-P) \geq 5$

Null Hypothesis: $H_0 : P = P_0$

Test statistic:

$$Z = \frac{p-P}{\sqrt{\frac{PQ}{n}}}$$

follows Standard normal distribution

Standard error of proportion$= \sqrt{\frac{PQ}{n}}$
95% confidence limits (that is $\alpha = 5\%$) for $P$ is

$$(p - 1.96\sqrt{\frac{pq}{n}}, p + 1.96\sqrt{\frac{pq}{n}})$$

# Problems on single proportion

1. 40 people were attacked by a disease and only 36 survived. At 5% LOS, test whether the survival rate attacked by this disease is more than 85 %.

## Solution:

Let $x$ denotes the number of people survived after getting attacked by a disease.

Here $x = 36, n = 40$

sample proportion $p = \frac{x}{n} = \frac{36}{40} = 0.9$

1: $H_0 : P = 0.85$ against $H_1 : P > 0.85$ (Right tailed test)

2: Level of significance $\alpha = 0.05$

3: Test Statistic:

Consider the conditions

$nP = 40 \times 0.85 = 34 > 5, \quad n(1 - P) = 40 \times 0.15 = 6 > 5$

# Problems

## Solution contd:

Hence,

$$Z = \frac{p - P}{\sqrt{\frac{PQ}{n}}} = \frac{0.9 - 0.85}{\sqrt{\frac{0.85 \times 0.15}{40}}}$$

$$= 0.8856$$

Note that $Z$ follows standard normal distribution.

4: Critical region:
$Z_\alpha = 1.65$. The critical region is $Z > 1.65$ Since Cal $Z = 0.8856$ lies in the acceptance region, we accept $H_0$ (or fail to reject $H_0$)

5: Conclusion:
There is no statistical evidence to prove that more than 85% of the people are attacked by a disease and survived.

# Test of difference of proportions

## Conditions

- $n_1 p_1 \geq 5; \qquad n_1 q_1 \geq 5; \qquad n_2 p_2 \geq 5; \qquad n_2 q_2 \geq 5$

Null Hyp $H_0 : P_1 - P_2 = d$ where $d$ is the difference in Population proportions.

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## Conditions

- $n_1 p_1 \geq 5; \qquad n_1 q_1 \geq 5; \qquad n_2 p_2 \geq 5; \qquad n_2 q_2 \geq 5$

Null Hyp $H_0 : P_1 - P_2 = d$ where $d$ is the difference in Population proportions.

Test statistic :

$$Z = \frac{(p_1 - p_2) - (P_1 - P_2)}{\sqrt{PQ(\frac{1}{n_1} + \frac{1}{n_2})}}$$

follows Standard normal distribution

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Test statistic :

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follows Standard normal distribution
If $P$ is unknown, then

$$P = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2}$$

# Problems

1. In a random sample of 100 men taken from Village A, 60 were found to be consuming alcohol. In another sample of 200 men taken from Village B, 100 were found to be consuming alcohol. Do the two villages differ significantly in respect to the proportion of men who consume alcohol?

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## Solution:

Let $x_1, x_2$ denotes the number of men consuming alcohol from Village A and B resptly.

Here $x_1 = 60, n_1 = 100, x_2 = 100, n_2 = 200$

sample proportion $p_1 = \frac{x_1}{n_1} = \frac{60}{100} = 0.6, p_2 = \frac{100}{200} = 0.5$

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1: $H_0 : P_1 - P_2 = 0$ against $H_1 : P_1 - P_2 \neq 0$ (Two tailed test)

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## Solution:

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Here $x_1 = 60, n_1 = 100, x_2 = 100, n_2 = 200$

sample proportion $p_1 = \frac{x_1}{n_1} = \frac{60}{100} = 0.6, p_2 = \frac{100}{200} = 0.5$

1: $H_0 : P_1 - P_2 = 0$ against $H_1 : P_1 - P_2 \neq 0$ (Two tailed test)

2: Level of significance $\alpha = 0.05$

3: Test Statistic:

Consider the conditions $n_1 p_1 = 100 \times 0.6 = 60 > 5, n_1 q_1 = 40 > 5, n_2 p_2 = 100 > 5, n_2 q_2 = 100 > 5$

# Problems

## Solution contd:

Hence,

$$P = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2} = \frac{100 \times 0.6 + 200 \times 0.5}{100 + 200} = 0.533$$

## Solution contd:

Hence,

$$P = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2} = \frac{100 \times 0.6 + 200 \times 0.5}{100 + 200} = 0.533$$

$$Z = \frac{(p_1 - p_2) - (P_1 - P_2)}{\sqrt{PQ(\frac{1}{n_1} + \frac{1}{n_2})}}$$

$$= \frac{0.1}{\sqrt{0.533 \times 0.467(\frac{1}{100} + \frac{1}{200})}}$$

$$= 1.6366$$

Note that $Z$ follows standard normal distribution.

## Solution contd:

4: Critical region:
Since it is a two tailed test , The critical value is $Z_{\frac{\alpha}{2}} = 1.96$.
The critical region is $|Z| \geq 1.96$. That is, critical region is
$-3 < Z \leq -1.96$ or $1.96 \leq Z < 3$
Since $-1.96 \leq$ Cal $Z = 1.6366 \leq 1.96$, we accept $H_0$ (or fail to reject $H_0$)

# Problems

## Solution contd:

4: Critical region:
Since it is a two tailed test , The critical value is $Z_{\frac{\alpha}{2}} = 1.96$.
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$-3 < Z \leq -1.96$ or $1.96 \leq Z < 3$
Since $-1.96 \leq$ Cal $Z = 1.6366 \leq 1.96$, we accept $H_0$ (or fail to reject $H_0$)

5: Conclusion:
There is no statistical evidence to prove that two villages differ significantly in respect of proportion.

# Test of single mean

## Conditions

- If Population standard deviation is known, proceed with z-test.
- If Population standard deviation is not known, then proceed with z-test if it is a large sample ($n \geq 30$). If small sample, proceed with t-test (We will study in Module 6).

# Test of single mean

Null Hyp $H_0 : \mu = \mu_0$

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follows Standard normal distribution

Standard error $= \frac{\sigma}{\sqrt{n}}$
95% confidence limits for the mean are

$$(\bar{x} - 1.96\frac{\sigma}{\sqrt{n}}, \bar{x} + 1.96\frac{\sigma}{\sqrt{n}})$$

# Problems

1. The mean lifetime of a sample of 100 tube lights produced by a company is found to be 1580 hours with standard deviation of 90 hours. Test the hypothesis at 1% LOS, that the mean life time of the tubes produced by the company is 1600 hours.

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$n = 100, \bar{x} = 1580, s = 90$

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**Solution:**

$n = 100, \bar{x} = 1580, s = 90$

1: $H_0 : \mu = 1600$ against $H_1 : \mu \neq 1600$ (Two tailed test)

# Problems

1. The mean lifetime of a sample of 100 tube lights produced by a company is found to be 1580 hours with standard deviation of 90 hours. Test the hypothesis at 1% LOS, that the mean life time of the tubes produced by the company is 1600 hours.

**Solution:**

$n = 100, \bar{x} = 1580, s = 90$

1: $H_0 : \mu = 1600$ against $H_1 : \mu \neq 1600$ (Two tailed test)

2: Level of significance $\alpha = 0.01$

# Problems

1. The mean lifetime of a sample of 100 tube lights produced by a company is found to be 1580 hours with standard deviation of 90 hours. Test the hypothesis at 1% LOS, that the mean life time of the tubes produced by the company is 1600 hours.

## Solution:

$n = 100, \bar{x} = 1580, s = 90$

1: $H_0 : \mu = 1600$ against $H_1 : \mu \neq 1600$ (Two tailed test)

2: Level of significance $\alpha = 0.01$

3: Test Statistic:
Since $n \geq 30, Z$ follows standard normal distribution.

$$Z = \frac{\bar{x} - \mu}{\frac{\sigma}{\sqrt{n}}} = -2.22$$

# Problems

## Solution contd:

4: Critical region:
Since it is a two tailed test , the critical value is $Z_{\frac{\alpha}{2}} = 2.58$
The critical region is $|Z| \geq 2.58$.
Note that Cal $Z = -2.22 \geq -2.58$, we accept $H_0$

5: Conclusion:
We conclude that the mean life time of the tubes produced by the company is 1600 hours.

# Test of difference of means

## Conditions

- If Population standard deviations are known, proceed with z-test.
- If Population standard deviations are not known, then proceed with z-test if both samples are such that $n_1 \geq 30$, and $n_2 \geq 30$. If small sample, proceed with t-test (We will study in Module 6).

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Null Hyp $H_0 : \mu_1 - \mu_2 = d$

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Null Hyp $H_0 : \mu_1 - \mu_2 = d$

Test statistic :

$$Z = \frac{(\bar{x_1} - \bar{x_2}) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

follows Standard normal distribution

# Problems

1. Intelligence test given to two groups of boys and girls gave the following information:

| | Mean score | SD | Number |
|---|---|---|---|
| Girls | 75 | 10 | 50 |
| Boys | 70 | 12 | 100 |

Is the difference in the mean scores of boys and girls statistically significant?

# Problems

1. Intelligence test given to two groups of boys and girls gave the following information:

| | Mean score | SD | Number |
|---|---|---|---|
| Girls | 75 | 10 | 50 |
| Boys | 70 | 12 | 100 |

Is the difference in the mean scores of boys and girls statistically significant?

**Solution:**

Here $\bar{x_1} = 75, \bar{x_2} = 70, s_1 = 10, s_2 = 12, n_1 = 50, n_2 = 100$.

1: $H_0 : \mu_1 - \mu_2 = 0$ against $H_1 : \mu_1 - \mu_2 \neq 0$ (Two tailed test)

2: Level of significance $\alpha = 0.05$

## Solution contd:

3: Test Statistic:
Since $n_1, n_2 \geq 30$, we proceed with $Z$-test.

$$Z = \frac{(\bar{x_1} - \bar{x_2}) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} = 2.6958$$

4: Critical region:
Since it is a two tailed test , $Z_{\frac{\alpha}{2}} = 1.96$. The critical region is $|Z| \geq 1.96$
Note that Cal $Z = 2.6958 \geq 1.96$, we reject $H_0$

5: Conclusion:
We conclude that the difference in the mean score of boys and girls is statistically significant.

# More problems- Test of single proportion

1. A sample poll of 100 voters chosen at random from all the voters in a given district indicated that 55% of them were in favour of a particular candidate. Find (i) 95% and (ii) 99% confidence limits for the proportion of all the voters in favour of this candidate.

## Solution

Given $n = 100, p = 0.55$ (proportion of voters favouring the candidate.

(i) $\alpha = 5\% = 0.05 \implies Z_{\frac{\alpha}{2}} = 1.96$

95% Confidence limits are given by $(p - 1.96\sqrt{\frac{pq}{n}}, p + 1.96\sqrt{\frac{pq}{n}})$

$$(0.55 - 1.96\sqrt{\frac{0.55 \times 0.45}{100}}, 0.55 + 1.96\sqrt{\frac{0.55 \times 0.45}{100}})$$

$$(0.4525, 0.6475)$$

## Solution contd.

(ii) $\alpha = 1\% = 0.01 \implies Z_{\frac{\alpha}{2}} = 2.58$

99% Confidence limits are given by $(p - 2.58\sqrt{\frac{pq}{n}}, p + 2.58\sqrt{\frac{pq}{n}})$

$$(0.55 - 2.58\sqrt{\frac{0.55 \times 0.45}{100}}, 0.55 + 2.58\sqrt{\frac{0.55 \times 0.45}{100}})$$

$$(0.4216, 0.6784)$$

2. The population proportion is expected to be around 0.7. Find the sample size needed to estimate the proportion within 0.02 with confidence level of 90%.

## Solution:

Given $P = 0.7, p - P = 0.02$

$\alpha = 10\% = 0.1 \implies Z_{\frac{\alpha}{2}} = 1.645$

We know that $Z_{\frac{\alpha}{2}} = \frac{p-P}{\sqrt{\frac{PQ}{n}}}$

$p - P = Z_{\frac{\alpha}{2}} \times \sqrt{\frac{PQ}{n}}$

$0.02 = 1.645 \times \sqrt{\frac{PQ}{n}} \implies n = 1420.7$

Hence, $n = 1421$ approx.

3. A die is thrown 9000 times and throw of 3 or 4 is observed 3240 times. Show that the die cannot be regarded as an unbiased one.

**Solution:**

Let $x$ be the number of times 3 or 4 occurs.

$n = 9000, x = 3240, p = \frac{3240}{9000} = 0.36$

1: $H_0 : P = \frac{1}{3}$ (unbiased) against $H_1 : P \neq \frac{1}{3}$ (biased, Two tailed test)

2: Level of significance $\alpha = 0.05$

3: Test Statistic:
Consider the conditions
$nP = 9000 \times 0.333 = 2997 > 5, \quad n(1-P) = 9000 \times 0.667 = 6003 > 5$

# Problems

## Solution contd:

Hence,

$$Z = \frac{p - P}{\sqrt{\frac{PQ}{n}}} = \frac{0.36 - 0.333}{\sqrt{\frac{0.333 \times 0.667}{9000}}} = 5.37$$

Note that $Z$ follows standard normal distribution.

4: Critical region:
$Z_{\frac{\alpha}{2}} = 1.96$. The critical region is $|Z| \geq 1.96$ Since Cal $Z = 5.37$ lies in the critical region, we reject $H_0$.

5: Conclusion:
We conclude that the die is biased.

# More problems- Test of difference of proportions

1.A cigarette manufacturing firm claims that its brand B cigarette outsells its brand A by 8%. If it is found that 42 out of a sample of 200 smokers prefer brand A and 18 out of another random sample of 100 smokers prefer brand B, test whether the 8% difference is a valid claim.

**Solution:**

Given $n_1 = 200, n_2 = 100, x_1 = 42, x_2 = 18$
$p_1 = \frac{42}{200} = 0.21, p_2 = \frac{18}{100} = 0.18$

1. $H_0 : P_1 - P_2 = 0.08$ against $H_1 : P_1 - P_2 < 0.08$ (Left tailed test)
2. LOS $\alpha = 5\% = 0.05$
3. $n_1 p_1 = 200 \times 0.21 = 42 > 5, n_1 q_1 = 200 \times 0.79 = 158 > 5, n_2 p_2 = 100 \times 0.18 = 18 > 5, n_2 q_2 = 82 > 5$
   $P = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2} = 0.2$

## Solution contd.

$$Z = \frac{(p_1 - p_2) - (P_1 - P_2)}{\sqrt{PQ(\frac{1}{n_1} + \frac{1}{n_2})}}$$

$$= \frac{(0.21 - 0.18) - 0.08}{\sqrt{0.2 \times 0.8(\frac{1}{200} + \frac{1}{100})}}$$

$$= -1.02$$

Note that $Z$ follows standard normal distribution.

4: Critical region:
Since it is a left tailed test , The critical value is $Z_\alpha = -1.645$.
The critical region is $Z \leq -1.645$.
Since Cal $Z = -1.02 \geq -1.645$, we accept $H_0$ (or fail to reject $H_0$)

## Solution contd.

$$Z = \frac{(p_1 - p_2) - (P_1 - P_2)}{\sqrt{PQ(\frac{1}{n_1} + \frac{1}{n_2})}}$$

$$= \frac{(0.21 - 0.18) - 0.08}{\sqrt{0.2 \times 0.8(\frac{1}{200} + \frac{1}{100})}}$$

$$= -1.02$$

Note that $Z$ follows standard normal distribution.

4: Critical region:
Since it is a left tailed test , The critical value is $Z_\alpha = -1.645$.
The critical region is $Z \leq -1.645$.
Since Cal $Z = -1.02 \geq -1.645$, we accept $H_0$ (or fail to reject $H_0$)

5: Conclusion:
The difference of 8% in the sale of two brands is a valid claim.

2. In a year, there are 956 births in a town A of which 52.5% were male, while in towns A and B combined, this proportion in a total of 1406 births was 0.496. Is there any significant difference in the proportion of male births in the two towns?

**Hint:**

$n_1 = 956, n_1 + n_2 = 1406 \implies n_2 = 450$
$p_1 = 0.525$, combined proportion is $0.496 = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2}$
Hence $p_2 = 0.434$.
$H_0 : P_1 - P_2 = 0$ against $H_1 : P_1 - P_2 \neq 0$ (two-tailed)
Cal $Z = 3.184$, $Z_{\frac{\alpha}{2}} = 1.96$
Cal $Z$ lies in the rejection region. Hence reject $H_0$ (there is significant difference in the proportion of male births in the two towns)

# More problems- Test of single mean

1. A sample of 900 members has a mean 3.4 cm and SD 2.61cm. Is the sample from a large population of mean 3.25cm and SD 2.61cm. If the population is normal and the mean is unknown, find the 95% confidence limits for the mean.

# More problems- Test of single mean

1. A sample of 900 members has a mean 3.4 cm and SD 2.61cm. Is the sample from a large population of mean 3.25cm and SD 2.61cm. If the population is normal and the mean is unknown, find the 95% confidence limits for the mean.

**Hint:**

Given $n = 900, \bar{x} = 3.4, s = \sigma = 2.61$.
$H_0 : \mu = 3.25$ against $H_1 : \mu \neq 3.25$
Cal $Z = 1.724$ and $Z_{\frac{\alpha}{2}} = 1.96$
Critical region is $|Z| > 1.96 \implies$ we accept $H_0$.
95% confidence interval is given by

$$(\bar{x} - 1.96\frac{\sigma}{\sqrt{n}}, \bar{x} + 1.96\frac{\sigma}{\sqrt{n}})$$

$$(3.23, 2.57)$$

# More problems- Test of difference of means

1. The mean production of wheat from a sample of 100 fields comes to 200 kg per acre and another sample of 150 fields gives a mean of 220 kg per acre. Assuming the SD of the yield at 11 kg for the universe, test if there is a significant difference between the means of the populations.

**Hint:**

Given $n_1 = 100, n_2 = 150, \bar{x_1} = 200, \bar{x_2} = 220, \sigma = 11$
$H_0 : \mu_1 - \mu_2 = 0$ against $H_1 : \mu_1 - \mu_2 \neq 0$ (Two tailed)
Cal $Z = -14.08$, $Z_{\frac{\alpha}{2}} = 1.96$
Since Cal $Z$ lies in the critical region $(-3 < Z < -1.96$ or $1.96 < Z < 3)$, we reject $H_0$
There is a significant difference between the means of the two populations.

# Try this

1. A sample of heights of 6400 Englishmen has a mean of 170cm and a SD of 6.4cm, while a sample of heights of 1600 Indians has a mean of 172cm and a SD of 6.3cm. Do the data indicate that Indians are on the average taller than Englishmen?
2. In city A, out of a sample of 50 persons, 26 were regular consumers of tea. In city B, out of a sample of 60 persons, 43 were regular consumers of tea. Test whether the tea consuming habit is equally distributed in both the cities at 5% level of significance.
3. A random sample of 50 observations from normal population gave an arithmetic mean of 32 units with a standard deviation of 2 units. Test whether the population mean is 30 at 1% LOS.
4. A sales clerk in a departmental store claims that 60% of the shoppers entering the store leave without making a purchase. A random sample of 50 shoppers showed that 35 of them left without buying anything. Are these sample results consistent with the claim of the sales clerk?