

# Final Sheet

December 2021

## 1 Data

### 1.a Types of Variables

#### **Qualitative/Categorical**

- Outcomes fall into different categories
- Categories can be ordered

#### **Quantitative**

- Measured on a numeric scale

### 1.b Summarizing Data Visually

#### **Qualitative/Categorical Data**

- Frequency tables - displays all categories of a single categorical variable with associated frequencies
- Contingency tables - display two categorical variables simultaneously
- Marginal distributions - display distribution of one of the two variables only
- Conditional distributions - display distribution of one variable, satisfying a condition of the other variable
- Bar charts
- Pie charts

#### **Quantitative Data**

- **Graphically**
  - Histogram
  - Stem-and-leaf displays
  - Boxplots
- **Shape of the Distribution**
  - Modality (number of peaks):
    - \* unimodal
    - \* bimodal
    - \* multimodal
  - Symmetry of distribution:
    - \* unimodal

- \* skewed to right (long right tail)
  - \* skewed to left (long left tail)
- Presence of outliers
- **Numerically**
  - Measures of center:
    - \* mean
    - \* median
  - Measures of spread:
    - \* variance:  $s^2 = \frac{\sum_{i=1}^n (y_i - \bar{y})^2}{n-1}$
    - \* standard deviation:  $s = \sqrt{\frac{\sum_{i=1}^n (y_i - \bar{y})^2}{n-1}}$
    - \* interquartile range  $IQR = Q3 - Q1$
  - Percentiles (also called quantiles)
  - 5-number summary:
    - \* minimum
    - \* first quartile (Q1)
    - \* second quartile (Q2)
    - \* third quartile (Q3)
    - \* maximum
- **Sensitivity to Outliers**
  - Sensitive to outliers:
    - \* mean
    - \* range, variance, standard deviation
  - Not sensitive to outliers
    - \* median
    - \* IQR

## 2 Normal Distribution

### Characteristics of the Normal Model

- bell-shaped; unimodal
- perfectly symmetric about the mean
- spread of distribution determined by value of standard deviation
- mean  $\mu$  and the standard deviation  $\sigma$  are parameters (numerical characteristics of a model)
- mean  $\bar{y}$  and standard deviation  $s$  are statistics (numerical characteristics of a sample)

### The 68-95-99.7 Rule

- 68% of data falls within 1  $\sigma$  of  $\mu$
- 95% of data falls within 2  $\sigma$  of  $\mu$
- 99.7% of data falls within 3  $\sigma$  of  $\mu$

## Finding Areas Under the Normal Model

### Algorithm

- Identify the:
  - $\mu$  - mean of the model
  - $\sigma$  - standard deviation of the model
  - $y$  - observed value
- Construct the normal model:  $N(\mu, \sigma)$
- Calculate the z-score ( $z$ ):  $z = \frac{y - \mu}{\sigma}$
- Using R compute the p-value:
  - Area below  $y$ :  $\text{pnorm}(z)$
  - Area above  $y$ :  $\text{pnorm}(z, \text{lower.tail} = \text{F})$
  - Area in between  $y_1$  and  $y_2$  (where  $y_1 > y_2$ ):  $\text{pnorm}(z_1) - \text{pnorm}(z_2)$
- **Finding Z-Score from the Area Under the Normal Model**
  - Area above unknown  $y$ :  $\text{qnorm}(p, \text{lower.tail} = \text{F})$
  - Area below unknown  $y$ :  $\text{qnorm}(p)$

## 3 Probability and Random Variables

### Determining Independence of Events

#### The Binomial Model

- Used for discrete random variables
- Binomial Model:
  - Experiment must consist of  $n$  identical trials (number of trials is fixed in advance)
  - Outcomes of each trial are either success or failure
  - Probability of success  $p$  is constant
  - Probability of failure is  $q = 1 - p$
  - The trials are independent
  - The random variable  $X$  represents the number of successes out of  $n$  trials

### Algorithm for the Probability of Binomials

- Identify the parameters:
  - $n$  - number of trials
  - $p$  - probability of success
- Construct the binomial model:  $X \sim \text{Bin}(n, p)$
- Calculate the probability:
  - Where the probability that  $X$  will take on value  $x$  is given by:  
 $P(X = x) = {}_n C_x p^x * (1 - p)^{n-x}, x = 0, 1, 2, \dots, n$
  - Where:  ${}_n C_x = \frac{n!}{x!(n-x)!}$

### Mean, Variance and Standard Deviation for a Random Binomial Variable

- Mean:  $np$   
Interp. average number of successes if you were to repeat experiment many times

- Variance:  $np(1 - p)$   
Interp. measure of variability of numbers of successes you were to repeat experiment many times
  - Standard deviation:  $\sqrt{np(1 - p)}$
- Uniform Random Variable**

## 4 Correlation and Association

### Scatterplots

- Direction:
  - Positive ( $x$  and  $y$ ) values tend to go in the same direction)
  - Negative ( $x$  and  $y$  values tend to go in the opposite direction)
- Form:
  - Linear
  - Non-linear
- Point relationship:
  - Strong relationship between points
  - weak or no relationship between points (randomly scattered)
- Outliers

### Correlation ( $r$ )

- Positive correlation: large  $x$  values are linearly associated with large  $y$  values ( $r$  is positive)
- Negative correlation: large  $x$  values are linearly associated with small  $y$  values ( $r$  is negative)
- $r$  has a value between 1 and -1, and has no units
- $r = \frac{\sum z_x * z_y}{n-1}$

### Association vs Causality

- Association does not imply causation. There may be a lurking variable

## 5 Regression Analysis

### The Regression Line

- Equation for regression line:  $\hat{y} = intercept + (slope * x)$
- Equation for slope:  $slope = r * \frac{s_y}{s_x}$   
(where  $s_y$  and  $s_x$  are the standard deviations of  $y$  and  $x$  respectively)
- Equation for intercept:  $intercept = \bar{y} - (slope * \bar{x})$   
(where  $\bar{y}$  and  $\bar{x}$  are the mean  $y$  and  $x$  values respectively)

### The Residuals

- The residual ( $e$ ) is the difference between observed value  $y$  and the predicted value  $\hat{y}$ . Therefore:  
 $e = y$  (from data) -  $\hat{y}$  (from model)
- The sum of residuals is equal to zero
- Linear model is obtained by minimizing the sum of the squared residuals. Therefore, also referred to as the least squares regression line
- To assess appropriateness of regression model, we use the residual plot (plots residuals against explanatory variable data). If plot shows no pattern, model is appropriate.

## 6 Experiments and Observational Studies

### Types of Studies

- Observational Studies
  - Investigators have no control over either variable
  - No deliberate human intervention
  - Retrospective study: based on information from events that have taken place in the past
  - Prospective study: data and information is gathered in real time
- Experiments
  - Involves planned intervention on the exposure to a condition suspected of altering the response outcome
  - Most often control group(s) will be used

### Randomized, Comparative Experiments

- Involves assessing the effect of an explanatory variable, called a factor, on a response variable
- Compares the response variable between different levels of the factor
- Experimenters control what type of treatment individuals receive, the treatment assignment is random
- Participants referred to as subjects or experimental units
- The treatment a subject receives will be a combination of the levels from different factors

### Principles of Experimental Design

- Randomize
  - Treatments are randomly assigned to subjects
- Replicate
  - Comparison between different treatment groups will not be reliable unless more individuals receive each treatment
- Blocking
  - May be beneficial to control for variables that are not factors but are believed to have some influence on the response variable
  - Subjects are divided into blocks (ex. male and female groups). Treatment assignment and comparisons are done within each block separately

### Blinding and Placebo

- Single Blind: either the subjects or the evaluators are blinded as to treatment assignment
- Double Blind: neither the subjects nor the evaluators knows the treatment assignments
- Blinding is usually done using a placebo which is designed to look like the treatment but has no real treatment value

## 7 Types of Sampling

### Sampling Methods

- Simple Random Sampling
  - Consists of  $n$  individuals sampled at random from the population
  - Each individual has an equal chance of being selected
  - Each possible sample size  $n$  is equally likely
- Stratified Sampling
  - Population is divided into strata (a stratum is a subset of the population that shares a particular characteristic)
  - Simple random sample is drawn from each stratum
  - Stratified sample has smaller variability across samples and hence give more reliable results
- Cluster Sampling
  - Can be used when natural groups in a population exist
  - Population is divided into those groups/clusters
  - Simple random sample from all clusters is obtained
  - If all individuals in a selected cluster are included, final sample is a one-stage cluster sample
  - If additional simple random sample is drawn from selected clusters, final sample is a two-stage cluster sample
  - This method is used for the sake of convenience, practicality, and cost-efficiency
- Multistage Sampling
  - Involves more than one stage or more than one sampling procedure in obtaining a sample
- Systematic Sampling
  - Obtained by selecting every  $k$ th individual from the sampling frame
  - Method can be used as long as list being sampled from does not contain a hidden order

### Bad Sampling Procedures and Biases

- Undercoverage
  - When sampling frame or sampling procedure excludes or under-represents certain types of individuals from the population
- Convenience Sampling
  - Selecting individuals from a population based on availability and access
- Voluntary Response Bias
  - If responses are voluntary, those with strong opinions tend to be over-represented
- Non-response Bias
  - Individuals who do not respond in a survey might differ from the respondents in certain aspects
  - Including only the respondents in a sample will result in non-response bias
- Response Bias
  - Subject's response is influenced by how the question was phrased or asked, or due to misunderstanding of a question, or unwillingness to disclose the truth

## 8 Sampling Distribution Models

### Basic Information

- Population: all individuals who want to be studied
- Sample: a subset of individuals selected from a population
- Parameter: a numerical summary of a population
- Statistic: a numerical summary of the sample

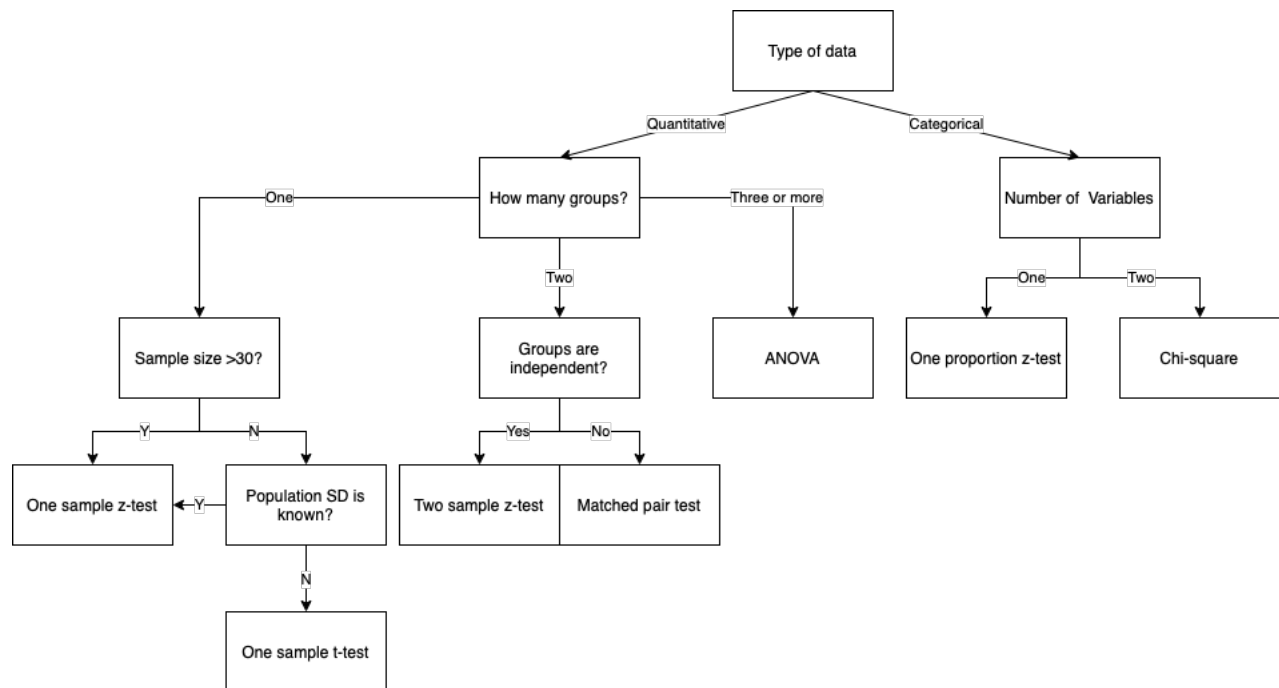
### Sampling Distribution of Proportions

- The sample proportion (a statistic) is given by:  
$$\hat{p} = \frac{\text{number of individuals sampled who have the characteristic}}{\text{sample size } n}$$
- Value of population proportion  $p$  is fixed, usually unknown. Therefore, sample proportion  $\hat{p}$  used to estimate
- Sampling distribution of  $\hat{p}$ :
  - mean  $\mu(\hat{p})$ : mean of  $\hat{p}$  = mean of  $p$
  - standard deviation  $\sigma(\hat{p})$ :  $\sqrt{\frac{p(1-p)}{n}}$
  - Sampling distribution of  $\hat{p}$  approximately normal when:
    - \* Sample is random
    - \* Individual values are independent (sample size  $\leq 10\%$  of population)
    - \* Sample size is large ( $np \geq 10$  and  $n(1-p) \geq 10$ )

### Sampling Distribution of Means

- The sample mean (a statistic) is given by:  
$$\bar{y} = \frac{y_1 + y_2 + \dots + y_n}{n}$$
- Population mean  $\mu$  is a parameter, fixed and usually unknown
- Sampling distribution of means:
  - mean  $\mu(\bar{y}) = \mu$
  - standard deviation  $\sigma(\bar{y}) = \frac{\sigma}{\sqrt{n}}$
- Central limit theorem (CLT)
  - For sufficiently large samples, sample mean approximately follows the normal model
  - Assumption for CLT are:
    - \* Sample is random
    - \* Individual values are independent (sample size  $\leq 10\%$  of population)
    - \* Sample size is sufficiently large (generally  $n \geq 30$ )

## 9 Hypothesis Testing



### 9.a One sample z-test

#### Algorithm

- Identify parameter of interest. Find the null and alternative hypotheses.  
 $s$  - The standard deviation of the sample.  
 $n$  - The sample size.  
 $\mu$  - Hypothesized population mean.  
 $SE(\bar{y}) = \frac{s}{\sqrt{n}}$  - Standard error of the statistic.
- Construct the null-model:  $N(\mu, \frac{s}{\sqrt{n}})$
- Find the test-statistic(t):  $Z = \frac{x - \mu}{SE(\bar{y})}$
- Using R compute the p-value:
  - One-sided hypothesis : `pnorm(t)`
  - Two-sided hypothesis : `2 * pnorm(t)`
- If the p-value is less than  $\alpha$  - reject the null-hypothesis. Otherwise, you fail to reject the null-hypothesis.

### 9.b One proportion z-test

#### Algorithm

- Identify parameter of interest. Find the null and alternative hypotheses.  
 $n$  - The sample size.  
 $p_0$  - Hypothesized proportion.  
 $SD = \sqrt{\frac{p_0(1-p_0)}{n}}$  - Standard error of the statistic.
- Construct the null-model:  $N(p_0, \sqrt{\frac{p_0(1-p_0)}{n}})$

- Find the test-statistic(t):  $Z = \frac{x - p_0}{SD}$
- Using R compute the p-value:
  - One-sided hypothesis : `pnorm(t)`
  - Two-sided hypothesis : `2 * pnorm(t)`
- If the p-value is less than  $\alpha$  - reject the null-hypothesis. Otherwise, you fail to reject the null-hypothesis.

### 9.c Two sample z-test

#### Algorithm

- Identify parameter of interest. Find the null and alternative hypotheses.
  - s - The standard deviation of the sample.
  - $n_1$  - The sample size of the first sample.
  - $n_2$  - The sample size of the second sample.
  - $\Delta_0$  - Hypothesized mean of difference between two populations.
  - $SD(\bar{y}_1 - \bar{y}_2) = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$  - Standard error of the statistic.
  - $df = \min(n_1 - 1, n_2 - 1)$
- Construct the null-model:  $N(\mu, \frac{s}{\sqrt{n}})$
- Using R compute the p-value:
  - One-sided hypothesis : `pnorm(t)`
  - Two-sided hypothesis : `2 * pnorm(t)`
- If the p-value is less than  $\alpha$  - reject the null-hypothesis. Otherwise, you fail to reject the null-hypothesis.

### 9.d Matched pair

#### Algorithm

- Identify parameter of interest. Find the null and alternative hypotheses.
  - $\Delta_0$  - Hypothesized population mean difference (usually 0)
  - $\bar{d}$  - The mean of the differences.
  - $s_d = \sqrt{\frac{\sum_{i=1}^n (d_i - \bar{d})^2}{n-1}}$  = The standard deviation of the sample differences.
  - n - The sample size.
- Find the test-statistic(t):  $t = \frac{\bar{d} - \Delta_0}{\frac{s_d}{\sqrt{n}}}$
- Using R compute find the p-value using pt function:
  - For one sided tests use: `pt(t, n-1)`
  - For two sided tests use: `2 * pt(t, n-1)`
- If the p-value is less than  $\alpha$  - reject the null-hypothesis. Otherwise, you fail to reject the null-hypothesis.

## 9.e One sample t-test

### Algorithm

- Identify parameter of interest. Find the null and alternative hypotheses.  
 $s$  - The standard deviation of the sample.  
 $n$  - The sample size.  
 $\mu$  - Hypothesized population mean.  
 $SE(\bar{y}) = \frac{s}{\sqrt{n}}$  - Standard error of the statistic.
- Construct the null-model:  $N(\mu, \frac{s}{\sqrt{n}})$
- Find the test-statistic(t):  $Z = \frac{\bar{y} - \mu}{SE(\bar{y})}$
- Using R compute find the p-value using pt function:
  - For one sided tests use:  $pt(t, n-1)$
  - For two sided tests use:  $2 \cdot pt(t, n-1)$

## 9.f ANOVA

- $k$  = number of groups.
- $N$  = number of subjects in total.
- $SSTo$  = Sum of Squares Total.
- $SSTo = SStr + SSEr$ .

Source of Variation	df	Sum of Squares (SS)	Mean Sum of Squares (MSS)	F-test	p-value
Treatment	k-1	SStr	$MSTr = SStr / (k-1)$	$F = MSTr / MSE$	
Error	N-k	SSE	$MSE = SSE / (N-k)$		
Total	N-1	SSTo			

- After filling the table with the values and finding F statistic, you can decide to reject the null-hypothesis or not based on two methods:
  - Method 1:
    - Compute critical value using R :  $qf(1 - \alpha, k - 1, N - k, lower.tail=TRUE)$
    - If F-statistic is greater than critical value - reject the null-hypothesis. Otherwise, you fail to reject the null-hypothesis.
  - Method 2:
    - Compute the pvalue using R:  $pf(F, k - 1, N - k, lower.tail=FALSE)$
    - If pvalue is less than  $\alpha$  - reject the null-hypothesis. Otherwise, you fail to reject the null-hypothesis.

### 9.g Chi-Square Test

- $n$  = number of groups.
- $c(kj\dots)$  = all observations from the table given where you enter the data for each row from left to right.
- Enter your data: `matrix(c( $k_i j \dots$ ), ncol= $n$ , byrow=TRUE)`
- Using R compute the p-value and test-statistic: `chisq.test(sample.data, correct=FALSE)`
- If the p-value is less than  $\alpha$  - reject the null-hypothesis. Otherwise, you fail to reject the null-hypothesis.
- Example:

	Heart disease	No heart disease	Total
High cholesterol diet	(i) 11	(iii) 4	15
Low cholesterol diet	(ii) 2	(iv) 6	8
	13	10	23

- Enter data into R: `matrix(c(11,4,2,6), ncol=2, byrow=TRUE)`
- Using `chisq` function compute test-statistic: `chisq.test(sample.data, correct=FALSE)`

#### Pearson's Chi-squared test

data: sample\_data

X-squared = 4.9597, df = 1, p-value = 0.02594

- At 5% confidence level we would reject the null-hypothesis, because the p-value is less than 5%.