# Course Revised Structure for the Two Years M.Sc.
# In
# **STATISTICS**
# 2016

## Department Of Statistics
## West Bengal State University
## Barasat, North 24-Pargans.

[With effect from Academic Year 2016-17]

**Objective & Outcome**

M. Sc. programme in statistics equips a graduate student to build a career in various disciplines; e.g., data sciences, health sciences, environmental sciences, medical research, pharmaceutical research, finance, public policy making, data analytics etc. In today's fast growing complex world Statistics becomes an important discipline both for researchers and job seekers. Students will learn an optimal blending of various statistical techniques and its' applications. These will help the students to acquire sufficient knowledge in Statistics so that the students can opt for an academic career or can prepare themselves for jobs in different private and public sectors. Moreover, this programme is structured in such a way that a B.Sc. student in Mathematics will be able to pursue it. After successful completion of the programme in Statistics, a student will:

- have the versatility to work effectively in a broad range of analytic, scientific, government, financial, health, technical and other positions,
- recognize the importance and value of statistical thinking, training, and approach to problem solving, on a diverse variety of disciplines,
- be familiar with a variety of examples where statistics helps accurately explain abstract or physical phenomena,
- be able to independently read statistical literature of various types, including survey articles, scholarly books, and online sources; and others,
- be life-long learners who are able to independently expand their statistical expertise when needed, or for interest's sake.

## Information on the M.Sc. in Statistics Examination

Conventionally a semester consists of 14 weeks and for a course carrying 1 Credit Point (CP), 14 lectures, each with one hour duration, is required.
The 1000 Marks, 80 CP course has been divided into 18 theoretical (700 Marks, 56 CP) and 8 experimental (300 Marks, 24 CP) courses. Experimental sections include Practical, Assignments and Seminar.
For each course, there will be an internal assessment based on a mid-semester examination carrying 20% of the total marks. However, the particulars of the examination (e.g. assessment and reassessment procedures), minimum qualifying marks for a course and for a semester will be in accordance with the existing university regulations.

## Courses Offered & Distribution of Marks

## Part 1, Semester I

*Theoretical Courses* (175 Marks, 14 CP)

STA 501 : Mathematical Methods (Linear Algebra & Real Analysis) [50 Marks, 4 CP]
STA 502: Descriptive Statistics (20 Marks), & Probability theory I (30 marks). [50 Marks, 4 CP]
STA 503 : Statistical Inference I (15 Marks), & Sampling distribution I (15 Marks); Survey Methodologies (20 marks). [50 Marks, 4 CP]
STA 504 : Regression Analysis I. [25 Marks, 2 CP]

*Practical Courses* (75 Marks, 6 CP)

STA 505 : Statistical Computing I [25 Marks, 2 CP]
STA 506 : Practical I [50 Marks, 4 CP]

*Examination for STA 505 will be computer based on the topics covered in C and R and STA 506 comprises of practical based on the topics in STA 502-504.*

## Part 1, Semester II

_*Theoretical Courses*_ (175 Marks, 14 CP)

STA 511 : Probability Theory II [50 Marks, 4 CP]
STA 512 : Sampling Distribution II (25 marks), & Statistical Inference II (25 marks) [50 Marks, 4 CP]
STA 513 : Linear Models (25 marks), & Regression Analysis II (25 marks) [50 Marks, 4 CP]
STA 514 : Designs of Experiment I [25 Marks, 2 CP]

_*Practical Courses*_ (75 Marks, 6 CP)

STA 515 : Statistical Computing II [25 Marks, 2 CP]
STA 516 : Practical II [50 Marks, 4 CP]

*Examination for STA 515 will be computer based on the topics covered in C and R and STA 516 comprises of practical based on the topics in STA 512-514.*

## Part 2, Semester I

_*Theoretical Courses*_ (175 Marks, 14 CP)

STA521 : Statistical Inference III (Decision theory & Bayesian Methods I) (25 mar), & Design of Experiments II (25 marks). [50 Marks, 4 CP]
STA522 : Regression Analysis III (25 marks), & Categorical Data Analysis (25 marks) [50 Marks, 4 CP]
STA523 : Statistical Inference IV (Asymptotic Methods, & Nonparametric Theory) [50 Marks, 4 CP]
STA524: Advanced Data Analysis [25 Marks, 2 CP]

*Practical Courses* (75  Marks, 6 CP)

STA 525 : Statistical Computing III [25 Marks, 2 CP]
STA 526 : Practical III [50 Marks, 4 CP]

*Examination for STA 525 will be computer based on the topics covered in C and R and STA 526 comprises of practical based on the topics in STA 521-524.*

## Part 2, Semester II

*Theoretical Courses* (175 Marks, 14 CP)

STA 531 : Stochastic Process (30 marks), & Time Series (20 marks) [50 Marks, 4 CP]
STA 532 : Advanced  paper I [50 Marks, 4 CP]
STA533 : Advanced Paper II [50 Marks, 4 CP]
STA 534 : Applied Multivariate Analysis [25 Marks, 2 CP]

*Practical Courses* (75  Marks, 6 CP)

STA 535 : Project Work [25 Marks, 2 CP]
STA 536 : Practical I [50 Marks, 4 CP]

*Examination for STA 526 comprises of practical based on the topics in STA 531-534.*

**Selection of the Advanced Papers (STA 532-533)**

For the selection of advanced papers (STA 532-533), students need to select any two of the following four modules and the courses thereof. However, the modules, as well as the optional papers within each module, to be offered in a particular year, will be decided by the Department.

**Module 1**: Survival Analysis and Bayesian Inference & Applications
Survival Analysis (25 marks); Bayesian Inference & Applications (25 marks)

**Module 2**: Advanced Survey Sampling
Advances Sample Survey (25 marks); Model-Dependent Inference In Survey Sampling (25 marks)

**Module 3**: Industrial Statistics
Operations Research (25 marks); Optimization (25 marks)

**Module 4**: Econometrics and Financial Statistics
Advanced Econometric Methods (25 marks); Statistics in Finance (25 marks)

# DETAILED SYLLABUS

## Part 1, Semester I [STA 501-506]

**Objective & Outcome**: This course is comprised of two important mathematical tools necessary for theoretical statistics. One is a foundation course on real analysis and another is an introductory course in linear algebra with emphasis on matrix algebra.

### STA 501: Mathematical Methods

*Linear Algebra*

Vector spaces with real field. Basis dimension of vector space. Orthogonal vectors, Gram-Schmidt orthogonalization. Linear transformation of matrices. Matrix operations. Elementary matrices and their uses. Rank of a matrix and related results. Inverse of a matrix. Determinants. Characteristic roots and vectors. Quadratic forms-classification and canonical reduction. Singular value decomposition. System of linear equations: homogenous and non-homogenous system. Generalized inverse: Moore-Penrose. Idempotent matrices and its properties. [15]

References

G. Hadley :Linear Algebra
K. M. Hoffman, & R. Kunze :Linear algebra
F.E. Graybill :Introduction to Matrices with Applications in Statistics
F. E. Hohn :Elements of Matrix Algebra
C. R. Rao :Linear Statistical Inference and Its Applications
S. R. Searle :Matrix Algebra Useful for Statistics
A.M. Goon :Vectors and matrices

*Real Analysis*

Real number system, cluster points of sets, closed and open sets, compact sets, Bolzano-Weierstrass property and Heine-Borel property-statement and applications. Sequences and Series of functions : pointwise convergence, uniform convergence, absolute convergence. Some tests of convergence. Continuity, uniform continuity, differentiability of univariate and multivariate functions. Mean value Theorem. Reimann integral and its properties. Reimann-Stieltjes integral. Review of sequence and series of functions. Uniform convergence: term by term differentiation and integration Power series. Taylor series expansion.
[35]

References

T.M. Apostal :Mathematical analysis
R. Rudin :Principles of Mathematical Analysis
R.R.Goldberg : Methods of Real Analysis
J.C.Burkill : First Course of Mathematical Analysis
J.C.Burkill, & H.Burkill : Second Course of Mathematical Analysis
R.G. Bartle, & D.R. Sherbert : Introduction to Real Analysis

**STA 502: Descriptive Statistics & Probability theory I**

**Objective & Outcome:** The course on descriptive statistics is useful for describing the basic features of data and its graphical displays. Another course, named Probability Theory I, offers mathematical foundation required for explaining/analyzing random phenomena. Here introductory classical probability theory will be taught. These two basic courses are specially designed for students with Mathematics background in B.Sc.

*Descriptive Statistics*

Introduction to Descriptive statistics. Univariate data – different measures of location, dispersion, relative dispersion, Skewness and kurtosis. Moments. Quantiles and measures based on them –comparison with moment measures. Gini's coefficient. Lorenz curve. Box Plot. Bivariate data – scatter diagram, correlation coefficient and its properties. Correlation ratio . Correlation Index. Intraclass correlation with equal and unequal group sizes. [20]

References

A.M. Goon, M.K. Gupta , & B. DasGupta. :Fundamentals of Statistics (vol.1)
G.U. Yule, & M.G. Kendall. :An introduction to the Theory of Statistics.
M.G. Kendall, & A. Stuart. : Advanced Theory of Statistics ( vols. 1-2)
G. W. Snedecor, & W.G. Cochran :Statistical Methods
F.F. Croxton, D.J. Cowden, & S. Klein. :Applied General Statistics,
F.E. Wallis, & H.V. Roberts :Statistics-a new approach.
J.W. Tukey :Exploratory Data Analysis
M.S. Lewis Beck (ed.) :Regression Analysis

*Probability Theory I*

Random Variables : Definition of discrete and continuous random variables. Cumulative distribution function and its properties (with proof), probability mass function and probability density function. Expectation and Moments, Dispersion, Skewness, Kurtosis, Quantiles. The cumulative distribution function, probability mass function and probability density function in bivariate case. Marginal and Conditional distributions. Independence. Conditional Expectation. Correlation and Regression. Generating Functions : probability generating function and moment generating function in univariate and bivariate cases. Probability Inequalities : Chebyshev's lemma, Markov's & Chebyshev's inequalities. Some univariate distributions. Bivariate Normal distributions and its properties. Limit Theorems : Convergence in probability, Weak law of large numbers and its applications. Convergence in distribution. De-Moivre-Laplace limit theorem, Normal approximation to the Poisson distribution. Statement of Central limit Theorem (independent and identically distributed sequence of random variables) and its application. [30]

References

K.L. Chung. :Elementary Probability Theory with Stochastic Process.
W. Feller :An introduction to Probability Theory & its application (vol. 1)

A.M. Goon, M.K. Gupta , & B. DasGupta. :An Outline of Statistical Theory (vol. – 1)
V.K. Rohatgi, & Md. E. Saleh. : An Introduction to Probability and Statistics
P.J. Hoel , S.C. Port, & C.J. Stone. :Introduction to Probability Theory (vol. 1)
G.C. Casella, & R.L. Berger. Statistical Inference
H. Cramer. :The Elements of Probability Theory
E. Parzen. : Modern Probability Theory and Its Application
J.V. Uspensky :Introduction to Mathematical Probability and Its Application
T. Cacoullos. : Exercises in Probability
N.A. Rahman. : Practical Exercises in Probability and Statistics
J. Pitman. : Probability
D. Stirzaker. : Elementary Probability
T.K. Chandra, & D. Chatterjee. : A First Course in Probability
R.R. Bhat : Modern Probability Theory
A. Gut. : An Intermediate Course In Probability
A. Dasgupta. : Fundamentals of Probability: A First Course

**STA 503: Sampling distribution I , Statistical Inference I, & Survey Methodologies.**

**Objectives & Outcome:** Three different courses, particularly for students from Mathematics at undergraduate, will be given here. In Sampling Distribution I students will learn the basic concepts of random sampling and distributions of some standard statistics (that is, functions of data/random sample) under a postulated model (e.g., normal population). The Statistical Inference I will provide basic ideas of inference from data; in particular, detail theory for point estimation. In Survey Methodologies students can learn the basic concepts of finite populations, drawing of samples by different sampling techniques from the populations, and related estimation of target quantities (that is, finite population parameters) like population mean, variances etc. Classical survey mythologies taught here will help students to understand how surveys are conducted in different public and private sectors.

*Sampling Distribution I*

Introduction : Concepts of random sampling. Statistic and its sampling distribution. Illustrations using different distributions, reproductive properties of the distributions.

Some standard Sampling Distributions : $\chi^2$ distribution, distributions of the mean and variance of a random sample from a normal population, *t* and *F* distributions, distributions of means, variances and correlation coefficient (null case) of a random sample from a bivariate normal population, distribution of simple regression coefficient (for both stochastic and non-stochastic independent variable cases). Distribution of order statistics and sample range. [15]

References

A.M. Goon, M.K. Gupta , & B. Das Gupta. : Fundamentals of Statistics (vol.1)
A.M. Goon, M.K. Gupta , & B. Das Gupta. : Outline of Statistics (vol.1)
C. R. Rao. : Advanced Statistical Methods In Biometric Research
R.V. Hogg, A.T Craig. :Introduction to Mathematical Statistics
G. Stuart, J.K. Ord : Advanced Theory of Statistics (vol. 2)
E.S. Keeping :Introduction to Statistical Inference.
G.K. Bhattacharya, & R.A. Johnson R.A.: Concepts & Methods Of Statistics
V.K. Rohatgi, & Md. E. Saleh. : An Introduction to Probability and Statistics
N.I. John, S. Kotz. :Distributions in Statistics
S.M. Ross. : Introduction to Probability Models.
A.M. Mood, F. Graybill, & D.C. Boes. : An Introduction to the Theory of Statistics

*Statistical Inference I*

Data reduction : Sufficiency and minimal sufficiency, Completeness, Bounded completeness and Ancillary Statistic. Exponential family of distributions.

*Point Estimation:* Concepts of point estimation. Requirement of a good estimator-notions of mean square errors., unbiasedness and minimum variance. Minimum variance unbiased estimators : Cramer-Rao lower bound, Rao-Blackwell, and Lehmann-Scheffe theorems. [15]

References

E. L. Lehmann, & G. Cesella. : Theory of Point Estimation
G.C. Casella, & R.L. Berger. Statistical Inference
S. Zacks. : Theory of Statistical Inference
S.S. Wilks. : Mathematical Statistics
V.K. Rohatgi, & Md. E. Saleh. : An Introduction to Probability and Statistics
A.M. Goon, M.K. Gupta , & B. DasGupta. :An Outline of Statistical Theory (vol. 2)

Nitis Mukhopadhyay. : Probability and Statistical Inference
R. W. Keener. : Theoretical Statistics: Topics for a Core Course

*Survey Methodologies*

Probability sampling from a finite population Basic sampling schemes : equal and unequal probability sampling with/without replacement. Related estimators of population total/mean, their variances and variance estimators. Horvitz Thompson, Hansen Horvitz, Des Raj and Murthy's estimator. Stratified sampling : allocation problem & the basic idea of optimal allocation, construction of strata. Basic ideas of Ratio, Product, Difference and Regression estimators. Unbiased Ratio type estimators. Hartley-Ross estimator in simple random sampling. Sampling and sub-sampling of clusters. Two-stage sampling, and double sampling. [20]

References

W.G. Cochran. : Sampling Techniques
Des Raj. : Sampling Theory
A.S.Hedayat & B.K.Sinha. :Design & inference in finite population sampling
P. Mukhopadhyay. : Theory & Methods of Survey Sampling
P. S. Levy, & S. Lemeshow. : Sampling of Populations: Methods and Applications
S. K. Thompson. : Sampling

**STA 504 : Regression Analysis I**

**Objective & Outcome:** This course is also specially designed for students from Mathematics background. Here students will learn the basic concepts of simple and multiple regressions are related theories. Importantly, here students will learn how to handle a prediction problem based on real data.

Simple Regression-related results. Multiple regression. Multiple correlation and partial correlation and their properties. Introduction : heterogeneity and analysis of variance (ANOVA) & covariance (ANCOVA). Linear hypothesis, orthogonal splitting of total variance, and selection of valid Error. Applications of the ANOVA technique : one-way classified data, two-way classified data with number of observations per cell, testing simple regression coefficients, correlation ratio, linearity of simple regression, multiple correlation and partial correlation coefficients. [25]

<u>References</u>

N. R. Draper, & H. Smith. : Applied Regression Analysis
A.M. Goon, M.K. Gupta , & B. DasGupta. :Fundamentals of Statistics (vols.1-2)
H. Sheffe : The Analysis of Variance
H. Sahai : The Analysis of Variance: fixed, random, and mixed models.
M.G. Kendall, & A. Stuart. : Advanced Theory of Statistics ( vol. 3)
A.M. Dean, & D. Voss : Design and Analysis of Experiments
O. Kempthrone :The Design and Analysis of Experiments
W.G. Cochran, & G. M. Cox. : Experimental Designs
D.C. Montgomery. : Design and Analysis of Experiments
P. Mukhopadhyay. : Applied Statistics
D.G. Montgomery, E.A. Peck, & G.G. Vining. : Introduction to Linear Regression Analysis

**STA 505 : Statistical Computing I**

**Objective & Outcome**: Introduction to classical C & modern R programming will be taught here. Programming is an integral part statistics in modern days since it helps to apply statistical theories in complex real world.

*Computing with C* : A brief overview of C: Syntax, loops, pointers, arrays, structures, functions, files. Review of statistical programming in C.
*Computing with R* : Basic operations: Basic arithmetic operations (addition, subtraction, multiplication, division etc): Use of R as a scientific calculator. Graphical display: Stem-leaf plot, Histogram and Density plot, Box plot, Scatter plot. Descriptive statistics: Simple Descriptive Measures (mean, variance, sum of squares, maximum, minimum, quantiles, correlation coefficient ). Sample drawing techniques: Drawing of random numbers, SRS procedure-with and without replacements..Matrix Calculations: Vectors and matrices: Basic operations on vector and matrices (addition, multiplication, calculation of quadratic forms).Determinant, Trace, Rank, Inverse and Solution of linear equations. Eigenvalues and Eigenvectors of a square symmetric matrix. Spectral Decomposition, Choleski Decomposition, Singular Value Decomposition of any matrix and rank determination. Moore-Penrose Generalized inverse using Singular Value Decomposition. [25]

References

B. W. Kernighan, & D.M. Ritchie. : The **C** Programming Language
H. Kanitkar. : Let us C
W. N. Venables and B. D. Ripley : Statistics: An introduction using R

Michael J. Crawley : Statistics: An introduction Using R
A. de Vries, & J. Meys. : R for Dummies.
K. Baclawski. : Introduction to Probability With R
A. Zuur, E.N. Leno, & E. Meesters. : A Beginner's Guide to R
P. Dalgaard. : Introductory statistics with R.

**STA 506 : Practical I**

**Objective& Outcome** In these courses practical necessary practical exercises related to theoretical courses taught and this course will help students to learn implementations of important statistical tools in real life data sets.

Practical exercises related to topics in STA 502-504. [50]

## Part 1, Semester II [STA 511-516]

**STA 511: Probability Theory II**

**Objective & Outcome**: Here rigorous measure theoretic probability theory will be taught. This course will help students in depth understanding of theoretical statistics. Specially, comprehensive understanding the large sample theories of statistics are heavily depend on this course.

Borel fields and sigma fields in probabily. Probability as a measure. Measurable functions: random variable as a measurable function. Integration of a measurable function with respect to a measure. Sequence of measurable functions: Monotone convergence theorem, Fatou's lemma and Dominated convergence theorem and their probabilistic aspects. Radon-Nikodym theorem (statement and application). Distribution functions: application of Lebesgue-Stieltje's measure. Expectation. Generating functions and Characteristic function. Inversion theorem and Continuity Theorem (only statement). Independence: Borel Cantelli Lemma. Sequence of random variables. Different modes of convergence of a sequence of random variables-inter-relations, Weak and Strong laws of large numbers. Kolmogorov's inequality. Central limit theorems (statement and applications). [50]

References

J. Jacod, & P. Protter. :Probability Essentials
K. B. Athereya, & S.N. Lahiri. : Measure Theory
K. B. Athereya, & S.N. Lahiri. : Probability Theory

A.K.Basu. : Measure Theory and Probability
B.R.Bhat. : Modern Probability Theory
P.Billingsley. : Probability and Measure
J.F.C. Kingman, & S.J. Taylor. : Introduction to Measure and Probability
R.G.Laha, & V.K. Rohatgi. : Probability theory
R. Ash. : Real Analysis and Probability
A. Gut : Probability : A Graduate Course
G. Grimmett, & D. Stirzaker. : One Thousand Exercises in Probability.

**STA 512: Sampling Distribution II, & Statistical Inference II**

**Objective & Outcome:** In Sampling Distribution II students get familiar with the concepts of multivariate normal distribution and the sampling distributions of some standard statistics under multivariate normal populations. This is an extremely important prerequisite for understanding of multivariate theories/ applications. Another course, Statistical Inference II, will impart students the theory of statistical hypothesis testing and confidence interval estimation. The testing problems have immense applications in different fields.

*Sampling Distribution II*

Concepts of non central distributions: $\chi^2$, $t$ and *F*. General discussion on multivariate distributions. Multivariate normal distribution and related results. Distribution of quadratic forms, Cochran's theorem. Random sampling from a multivariate normal distribution: Wishart matrix and its distribution (without derivation) and properties. Hotelling $T^2$ statistics: its distribution and related results. Mahalanobis $D^2$ statistics.

[25]

References

C. R. Rao. : Linear Statistical Inference and Its Applications
T. W. Anderson. : Introduction to Multivariate Analysis
S. S. Wilks. : Mathematical Statistics
A. M. Khirsagar. : Multivariate Analysis
C.G. Khatri, & M.S. Srivastava. : Introduction to Multivariate Statistics
R. J. Muirhead. : Aspects of Multivariate Statistical Theory
G. A. F. Seber. : Multivariate Observations
M. Bioodeau, & D. Brenner. : Theory of Multivariate Statistics

*Statistical Inference II*

*Testing Of Hypothesis* Nonrandomized and Randomized tests, critical function, power function. Most Powerful (MP) Tests: Neyman-Pearson Lemma (Existence, Sufficiency and Necessity). Uniformly most powerful (UMP) tests: simple problems for exponential and pitman families of distributions. Enlargement technique for testing a composite null against a composite alternative. UMP tests for monotone likelihood ratio (MLR) families. Generalised Neyman-Pearson Lemma: uniformly most powerful unbiased (UMPU) tests for one parameter exponential families. Ideas of similar tests.

*Sequential Analysis* Sequential Probability ratio test (SPRT). Wald's equation (without proof). Optimality of SPRT. Wald's fundamental identity (without proof). SPRT of one sided test.

*Confidence Interval Estimation* Relation with hypothesis testing. Optimum parametric confidence intervals. [25]

References

E. L. Lehmann, & J. P. Romano. : Testing Statistical Hypotheses
G.C. Casella, & R.L. Berger. Statistical Inference
S. Zacks. : Theory of Statistical Inference
S.S. Wilks. : Mathematical Statistics
V.K. Rohatgi, & Md. E. Saleh. : An Introduction to Probability and Statistics
A.M. Goon, M.K. Gupta , & B. DasGupta. :An Outline of Statistical Theory (vol. 2)
Nitis Mukhopadhyay. : Probability and Statistical Inference
R. W. Keener. : Theoretical Statistics: Topics for a Core Course

**STA 513: Linear Models, & Regression Analysis II**

**Objective & Outcome:** In Linear Models students will learn detailed theoretical development for Gauss-Markov models and related inferences; and its applications in regression problems. Regression Analysis II, consists of theoretical developments for inferences under deviations from Gauss-Markov models. Here concepts of outliers and robust regression will be introduced to students. Students will be able to investigate validity of the regression models in practical situations.

*Linear Models*

Gauss-Markov model. Estimable functions. Best linear unbiased estimator (BLUE). Gauss Markov Theorem. Estimation space and error space. Sum of squares due to a set of linear functions. Estimation with correlated observations.

Least Square estimation with linear restriction on the parameters. General linear hypothesis: *F* test for general linear hypothesis and associated confidence sets. Multiple comparison procedures of Scheffe and Tukey. Applications of general linear hypothesis to regression. Analysis of variance and covariance (ANOVA & ANCOVA). Introduction to random and mixed effect models (balanced case). [25]

References

H. Scheffe. : Analysis of Variance
S. R. Searle. : Linear Models
G. A. F. Seber, & A.J. Lee. : Linear Regression Analysis
N. Giri. : Analysis of Variance
D. D. Joshi. : Linear Estimation & Design of Experiments
C. R. Rao. : Linear Statistical Inference and its Applications
R. B. Bapat. : Linear Algebra and Linear Models
R. W. Keener. : Theoretical Statistics: Topics for a Core Course

*<u>Regression Analysis II</u>*

Regression with one explanatory variable. Direct, reverse, orthogonal, and least absolute deviation (LAD) regressions with applications. Weighted least squares technique. Tests of fit of a model. Detection of outliers. Residual analysis: residuals and their plots. Departures from the usual assumptions: heteroscedasticity, autocorrelation, multicollinearity, Non-normality- detection and remedies. Model selection.

[25]

References

H. Scheffe. : The Analysis of Variance
A. Sen, & M. Srivastava.: Regression Analysis: Theory, Methods, and Applications
S. Chatterjee, & A. S. Hadi. : Sensitivity Analysis in Linear Regression
S. Chatterjee, & A.S. Hadi. : Regression Analysis by Example
S. Weisberg. : Applied Linear Regression
J. Fox. : Regression Diagnostics: An Introduction
D. A. Belsley, E. Kuh, & R. E. Welsch. : regression Diagnostics: Identifying Influential Data and Sources of Collinearity.
S. R. Searle. : Linear Models
G. A. F. Seber. : Linear Regression Analysis
N. Giri. : Linear Estimation & Design of Experiments

**STA 514: Designs of Experiment I**

**Objective & Outcome:** In this course students will be taught the concepts of controlled experiments and related inference problems. It has enormous applications in designs and analysis of experiments in the physical, chemical, biological, medical, social, psychological, economic, engineering, agricultural, or industrial sciences. The course will examine how to design experiments, carry them out, and analyze the data they yield. Upon completion, students will be able to understand the issues and principles of Design of experiments.

Basic principles of experimental design: randomization, replication, and local control. Uniformity trials. Shapes and sizes of plots and blocks. Standard designs and their analyses : completely randomised design (CRD), randomised block design (RBD), latin square design (LSD), split plot design, and strip arrangements. Comparison of efficiencies. Applications of the techniques of analysis of variance to the analysis of the above designs. Groups of experiments using RBD and LSD. General block designs and its information matrix. Concepts of connectedness, orthogonality, and balance. Intrablock analysis of orthogonal (CRD, RBD, LSD) and non-orthogonal designs (Balanced incomplete block design (BIBD), and Youden square design (YSD)). Recovery of interblock information in BIBD. [25]

References

O. Kempthrone. : The Design and Analysis of Experiments
M. N. Das, & N. C. Giri. : Design and Analysis of Experiments
D. C. Montgomery. : Design and Analysis of Experiments
W. G. Cochran, G.M. Cox. : Experimental Designs.
W. T. Federer. : Experimental Designs – Theory and Application
A.M. Goon, M.K. Gupta , & B. DasGupta. :Fundamentals of Statistics (vol. 2)
A.M. Dean, & D. Voss : Design and Analysis of Experiments
M. C. Chakraborty. : Mathematics of Design and Analysis of Experiments
A. Dey. : Theory of Block Designs
D. Raghavarao. : Constructions & Combinatorial Problems in Design of Experiments
R. C. Bose. : On the Construction of Balanced Incomplete Block. (Annals Eugenics, vol. 9)

**STA 515: Statistical Computing II**

**Objective & Outcome:** This a continuation of computing course in Semester 1. Simulations will be taught in C programming; while in R, data manipulation, statistical distributions, regressions will be taught using R functions.

*Computing in C* Stochastic simulation: generation of random numbers and selection of samples, and Monte Carlo simulation.

*Computing with R* Data manipulation : built-in datasets in R, read.table() and write.table() functions, and importing data from external sources. The built-in distributions in R : c.d.f., p.d.f./ p.m.f. , densities, quantiles, and random samples. Statistical inference: one sample and two sample problems, ANOVA, Goodness of fit tests. Regression Analysis: multiple linear regression using lm() function and related inferences and diagnostics. Weighted least squares. Measures of identifying unusual observations using in-built R functions (influence.measures(), dfbetas(), dffits(), cook.distance()). Box-Cox Transformation, Q-Q plot, Shapiro-Wilk Test.

[25]

References:

B. W. Kernighan, & D.M. Ritchie. : The **C** Programming Language

H. Kanitkar. : Let us C

R. Chakraborty. : Statistical Analysis using C: The Art of Statistical Computing.
W. H. Press et al. : Numerical Recipes Using C : The Art of Scientific Computing
J. F. Faraway. : Linear Models with R
J. F. Faraway.: Practical Regression and ANOVA Using R
J. Fox., & S. Weisberg. : An R Companion To Applied Regression

**STA 516: Practical II**

Objective & Outcome: In these courses practical necessary practical exercises related to theoretical courses taught and this course will help students to learn implementations of important statistical tools in real life data sets.

Practical exercises related to topics in STA 512-514. [50]

## Part 2, Semester I [STA 521-526]

### STA 521: Statistical Inference III, & Design of Experiments II

**Objectives & Outcome:** The course Statistical Inference III will impart introductory idea of decision theory and Bayesian methods. In Decision theory classical inference problems are viewed as a risk minimization problem and optimum rules are evaluated. This is a theoretical course. Bayesian methods will introduce basic ideas of another kind of statistical theory for inference on complex random phenomena. In this course students will be taught the concepts of controlled experiments and related inference problems. It has enormous applications in designs and analysis of experiments in the physical, chemical, biological, medical, social, psychological, economic, engineering, agricultural, or industrial sciences. The course will examine how to design experiments, carry them out, and analyze the data they yield. Upon completion, students will be able to understand the issues and principles of Design of experiments.

*Statistical Inference III : Decision Theory*

Loss, Decision rules and Risk function, Admissibility of decision rules, Bayes and Minimax rules. [10]

*Statistical Inference III : Bayesian Methods*

Overview and comparison of different paradigms, Relative advantages and disadvantages. Priors & Posteriors : Subjective priors, Conjugate and other Non-subjective priors. Bayesian Inference – estimation, testing, interval estimation and prediction for some common models and common priors. Hierarchical and Empirical Bayes Methods. Bayesian Computation. [15]

References

T.S. Ferguson. : Mathematical Statistics
E. L. Lehmann, & G. Cesella. : Theory of Point Estimation
J. O. Berger. : Statistical Decision Theory and Bayesian Analysis
H. Raiffa. : Applied Statistical Decision Theory
J. Pratt, & H. Raiffa. : Introduction To Statistical Decision Theory
F. Liese., & K.-J. Miescke. : Statistical Decision Theory
P. D. Hoff. : A First Course in Bayesian Statistical Methods
G. E. P. Box, & G. C. Tiao. : Bayesian Inference in Statistical Analysis
W. M. Bolsted. : Introduction to Bayesian Statistics
L. Held., & D. S. Bove. : Applied Statistical Inference: Likelihood and Bayes.
J.-M. Marin, & C.P. Robert. : Bayesian Essentials with R
J. Albrt. : Bayesian Computation with R

*Design of Experiments II*

Construction of complete classes of Mutually Orthogonal Latin Squares ( MOLS).Construction of BIBD using MOLS and Boses's fundamental method of difference. Factorial experiment: Confounding and balancing in symmetric factorial experiments- Analysis. [25]

References

M. C. Chakraborty. : Mathematics of Design and Analysis of Experiments
A. Dey. : Theory of Block Designs
D. Raghavarao. : Constructions & Combinatorial Problems in Design of Experiments
R. C. Bose. : On the Construction of Balanced Incomplete Block. (Annals Eugenics, vol. 9)
R. C. Bose. : Mathematical Theory of Symmetric Factorial (Sankhya, Vol. 8)

**STA 522: Regression Analysis III, & Categorical Data Analysis**

**Objective & Outcome** : In previous two courses on regression analysis students will learn to deal with regression problems and related diagnostics when response is continuous. But here students will primarily learn to develop regression when responses are binary, count or categorical in nature. Regression Analysis III will give theoretical treatments to regression when responses are assumed to belong to an exponential family of distributions (called GLM). Categorical Data Analysis course will teach students regression theories for nominal/ordinal responses. This course has many practical applications in different fields of studies.

*Regression Analysis III*

Generalized Linear Models (GLM): Introduction, components, goodness of fit measures-residuals and deviance. Inference for GLM. Applications to binary, count and polytomous data. Over dispersion. Marginal, conditional and quasi likelihood functions. Robust regression. [25]

References

P. McCullagh, & J. L. Nelder. : Generalized Linear Models
A. Dobson, & A. Barnett. : An Introduction to Generalized Linear Models
J. K. Lindasy. : Applying Generalized Linear Models
C. E. McCullagh, S.R. Searle, & J. M. Neuhaus.: Generalized, Linear, and Mixed Models
J. J. Faraway. : Extending the Linear Model with R
A. Agresti. : Foundations of Linear, and Generalized Linear Models

*Categorical Data Analysis*

Categorical Response Data: Nominal/ Ordinal Distinction, Probability Distributions for Categorical Data-Binomial& Multinomial Distributions. Inference for a proportion: Wald, Score, and Likelihood-Ratio Inference for Binomial Parameter. Contingency Tables**:** Probability Structure for Contingency Tables: Joint, Marginal, and Conditional Probabilities, Relative risk and odds ratio-properties. Measures of association and tests for independence in contingency tables: Nominal-Nominal, Ordinal – Ordinal and Nominal–Ordinal Tables. Exact Inference for Small Samples- Fisher's Exact Test for 2 × 2 Tables. Association in more than two-way classified data: Partial association, Conditional Versus Marginal Associations- Simpson's Paradox, Conditional and Marginal Odds, log-odds ratio and its distribution, Independence-Conditional Versus Marginal. [25]

References

A. Agresti. : Categorical Data Analysis
A. Agresti. : Analysis of Ordinal Categorical Data
A. Agresti. : Introduction to Categorical Data Analysis
J. S. Simonoff. : Analyzing Categorical Data

**STA 523: Statistical Inference IV**

**Objective & Outcome** : In the first part of this statistical inference course students will learn classical frequentist approach for parametric inference based on approximate distributions of the statistics in large samples. This enables students to draw inference based on statistics whose exact sampling distributions are very difficult to evaluate analytically. This course is an important prerequisite for learning advanced data analysis. In the second part of the course students will learn to draw distribution-free nonparametric inference in classical testing problems along with an introductory discussion on nonparametric density estimation problem.

*Asymptotic Methods*

Large sample properties of estimators: Consistency, Efficiency and Asymptotic Normality-CAN and BAN estimators. Maximum likelihood method of estimation (MLE) - Large sample properties. Likelihood ratio, Rao and Wald tests for simple and composite hypotheses- properties and asymptotic distribution of test criteria in the simple hypothesis case.
[25]
References

E. L. Lehmann. : Elements of Large-Sample Theory
E. L. Lehmann, & G. Cesella. : Theory of Point Estimation
T. S. Ferguson. : A Course in Large Sample Theory
P. K. Sen, & Singer. :Large Sample Methods in Statistics: An Introduction with Application
R. J. Serfling. : Approximation Theorems in Mathematical Statistics.
A. C. P. de Lima, J. M. Singer, & P. K. Sen. : From Finite sample To Asymptotic Methods in Statistics.
T. K. Chandra. : A First Course in Asymptotic Theory of Statistics
J. Jiang. : Large sample Techniques for Statistics
A. Dasgupta. : Asymptotic Theory of Statistics and Probability
D. D. Boos, & L L. Stefanski. : Essential Statistical Inferenc: Theory and Methods
R. W. Keener. : Theoretical Statistics: Topics for a Core Course

*Nonparametric Theory*

U-statistics- Definition and Asymptotic properties. Nonparametric tests: Single sample Problems: Location, Location-cum-symmetry, and Goodness-of-fit problems. Two-sample Problems: Location, Scale and Homogeneity problems. Multi-sample location problem. Friedman Two-way Analysis of variance problem. Bivariate association problem, Cochran Q-test for dependent samples. Nonparametric Interval Estimation. Concept of Asymptotic Relative Efficiency. Nonparametric Density Estimation.

[25]

References

J. D. Gibbons. : Nonparametric Inference
J. D. Gibbons, & S. Chakraborty. : Nonparametric Statistical Inference
T. P. Hettmansperger. : Statistical Inference Based on Ranks
E. L. Lehmann. : Statistical Methods based on Ranks
M. Hollander, D. A. Wolfe, & E. Chicken. : Applied Nonparametric Statistics
P. Sprent, & N. C. Smeeton. : Applied Nonparametric Statistical Method
S. Bonnini et al. : Nonparametric Hypothesis Testing
L. Wasserman. : All in Nonparametric Statistics

**STA 524: Advanced Data Analysis**

**Objective & Outcome:** This course comprises of three different topics. The first topic will introduce students how to build models for a non-cross-sectional type data called longitudinal or panel data. In other two topics, Missing Data Mechanism and Re-Sampling Techniques, students will learn two very practical techniques in Statistics. Missing data is a part of all most all real life surveys. Students will learn how to use missing data sets efficiently for estimation problems. In modern era of high level extensive computing, Re-sampling methods for drawing inference, particularly bootstrap, becomes extremely popular in practice since its implementation does not require theoretical knowledge of statistics. Here students will learn basic theoretical understanding of re-sampling theory and its implementations. In view of above facts this course can be viewed as a **skill development** course in Statistics.

*Longitudinal Data* Introduction with motivation, Exploring longitudinal
Data with some specific dependence structure

*Missing data mechanism* Inference for data with missing values. Different types of missing data mechanism. MLE using E-M algorithms. Various imputation techniques.

*Re-sampling Techniques*- Introduction to Jackknife and Bootstrap – methods for estimating bias ,standard error and distribution function based on i.i.d. random variables. Standard examples. Justification of the methods in i.i.d. set-up, Bootstrap confidence intervals, Computational aspects. [25]

References

P. Diggle et al. : Analysis of Longitudinal Data
G. Fitzmaurice, N. M. Laird, & J. H. Ware. : Applied Longitudinal Analysis
R. E. Weiss. : Modeling Longitudinal Data
D. Hedeker, & R. D. Gibbons. : Longitudinal Data Analysis
R. J. A Little, & D. B. Rubin. : Statistical Analysis with Missing Data
P. A. Allison. : Missing Data
C. K. Enders. : Applied Missing Data Analysis
D. F. Heitjan, & S. Basu. : Distinguishing "Missing at Random" and "Missing Completely at Random" (The American Statistician, Vol. 50)
T. Raghunathan. : Missing Data Analysis in Practice
B. Efron & R. J. Tibshirani. : An Introduction to the Bootstrap
A. C. Davison, & D.V. Hinkley. :Bootstrap Methods and Their Applications
J. Shao, & D. Tu. : The Jackknife and Bootstrap
M. R. Chernick, & R. A. LaBudde. : An Introduction to Bootstrap Methods with Applicatiosn to R

**STA 525: Statistical Computing III**

**Objective & Outcome: Objectives & Outcomes**: This is a continuation of computing courses in M.Sc. Part I. Numerical methods and programming will be taught C and R programming. This course will be very handy for project work in final semester.

*Advanced Computing with C* Numerical methods (Iteration, Newton-Raphson, Quasi-Newton algorithms) with C.
*Advanced Computing with R* Creating user defined functions: Conditional statements, loops, arrays. Numerical optimization: Solution of numerical equations (single unknown)- Maximum Likelihood Estimates, Nonlinear regression(nls() and nlm() functions). Numerical Integration: Numerical evaluation of probabilities involving one and two random variables. Simulation: Simulating functions of random variables.

References

W. H. Press et al. : Numerical Recipes Using C : The Art of Scientific Computing

V. A. Bloomfield. : Using R for Numerical Analysis in Science and Engineering
N. Matloff. : The Art of R Programming

**STA 526: Practical III**

**Objective & Outcome: Objectives & Outcomes**: In these courses practical necessary practical exercises related to theoretical courses taught and this course will help students to learn implementations of important statistical tools in real life data sets.

Practical exercises related to topics in STA 521-524.

## Part 2, Semester II [STA 531-536]

**STA 531: Stochastic Process, & Time Series**

**Objective & Outcome:** Here theory of different dependent processes will be taught to students. These processes are developed to model real life random phenomena from various fields of sciences and social sciences where underlying random variables are dependent in nature. In Time Series course students will experience introductory theoretical developments for particular type of dependency, known as time dependency.

*Stochastic Process*

Markov chain with finite state space and countable state space, Classification of states, Chapman-Kolmogorov equation, Calculation of n-step transition probability matrix and its limit, Stationary distribution of Markov chain, Random walk. Discrete state space continuous time Markov chains, Poisson process. Renewal theory: Elementary Renewal theorem, Stopping time, Statement and uses of Key Renewal theorem. Continuous process: Brownian motion. [30]

References

S. Karlin, & H. M. Taylor. : A First Course in Stochastic Processes
S. Ross. : Stochastic Process
J. L. Doob. : Stochastic Process
J. Medhi. : Stochastic Process
A. K. Basu. : Stochastic Process
P. G. Hoel, S. C. Port, & C. J. Stone C.J . : An Introduction to Stochastic Process

D. R .Cox. : Renewal Theory

*Time Series Analysis*

Stationary Time Series, linear process, causality and Invertibility, properties of linear stationary process, autocovariance function (ACVF) and partial autocorrelation function (PACF), methods of finding ACVF, ARMA process as particular case. Forecasting a time series, Best linear unbiased predictor, Iterative methods (Durbin -Levinson and Innovations Algorithm) of finding predictor with ARMA process as a particular case. [20]

References

C. Chatfield. : The Analysis of Time Series - An Introduction
G. E. P.Box, G. M. Jenkins & G.C.Reinsel. : Time Series Analysis - Forecasting and Control
G. Jancek & L. Swift. : Time Series - Forecasting, Simulation, Applications
P. J. Brockwell & R. A. Davis. : Introduction to Time Series and Forecasting
P. J. Brockwell & R. A. Davis. : Time Series: Theory and Methods
P.S. P. Cowpertwait & A.V. Metcalfe. : Introductory Time Series with R
R.H. Shumway & D. S. Stoffer. : Time Series Analysis & Its Applications
J.D. Cryer & K.-S. Chan. : Time Series Analysis: with Application in R

**STA 532: Advanced Paper I**

**STA 533: Advanced Paper II**

**STA 534: Applied Multivariate Analysis**

**Objective & Outcome:** This is extremely useful course consists of important multivariate real life problems like Principal components analysis, classification and discrimination problems, factor analysis and cluster analysis. In practice survey data are generally multivariate in nature and these techniques will help students to perform exploratory data analysis to survey data to revel important conclusions about the underlying populations. These techniques are very common in any field where data based conclusions are to be drawn; particularly in Analytics. This course develops important **skills** to handle multivariate problems.

Hierarchical and non-hierarchical clustering methods. Classification and discrimination procedures for discrimination between two known populations – Bayes, Minimax and Likelihood Ratio procedures. Discrimination between two multivariate normal populations. Sample discriminant function. Likelihood ratio rule. Tests associated with discriminant function, Probabilities of misclassification and their estimation. Classification of several populations. Fisher's method for discriminating among several populations. Population and sample principal components and their uses and related large sample inference. The orthogonal factor model, Estimation of factor loading, Factor rotation, Estimation of Factor scores, Interpretation of Factor Analysis.

[25]

References

R. A. Johnson & D. W. Wichern. : Applied Multivariate Statistical Analysis
N. H. Timm. : Applied Multivariate Analysis
A. V. Rencher & W. F. Christensen. : Methods of Multivariate Analysis
W. K. Hardle & L. Simar. : Applied Multivariate Statistical Analysis
W. K. Hardle & Z. Hlavka. : Multivariate Statistics: Exercises and Solutions
T. W. Anderson.: An Introduction to Multivariate Statistical Analysis
G. A. F. Seber.: Multivariate Observations
B. Everitt & T. Hothorn. : An Introduction Applied Multivariate Analysis with R

**STA 535: Project Work**

**Objective & Outcome:** Students will independently solve theoretical/ empirical statistical problems.

Theory and / or application of statistical methods.

**STA 536: Practical IV**

**Objective & Outcome: Objectives & Outcomes**: In these courses practical necessary practical exercises related to theoretical courses taught and this course will help students to learn implementations of important statistical tools in real life data sets.

Practical exercises related to topics in STA 531-534.

## Advanced Papers

**Module I : Survival Analysis, & Bayesian Inference & Applications**

**Objective & Outcome**: This module is partially helpful for students who are interested in **Biostatistics or Medical Statistics**. The Survival Analysis course will focus on basic concepts of survival (time-to-event) data analysis. Some of the important features that students are expected to learn in this course are: (a) understanding of different types of censoring, and learn to estimate and interpret survival characteristics; (b) assess the relationship of risk factors and survival times using the Cox regression model, and assess the appropriateness and adequacy of the model; and (c) development of analytic skills through the analysis of data sets taken from the fields of medicine and public health. Another topic in this course is Bayesian Methods II. In this course student will learn Bayesian linear and no nonlinear regressions, Bayesian estimation and testing problems and Bayesian computation & simulations (MCMC, Gibbs sampling and MH algorithm). This course in Bayesian inference will enable students to perform Bayesian data analysis in many real life complex problems.

*Survival Analysis*

Concepts of lifetime, Various schemes of censoring and associated likelihoods. Estimation of survival function: Parametric procedure: Point estimation, Scores and likelihood ratio tests for selected parametric models and confidence intervals. Distribution free procedures: Actuarial estimator, Kaplan-Meier and Nelson – Aalen estimators. Regression models: Estimation in parametric and Semi-parametric models-Cox's proportional hazard model, Time dependent covariates, Rank test. Competing risk analysis and Multivariate models.

[25]

References

D. J. Kleinbaum & M. Klein. : Survival Analysais : A Self-Learning Text

D. W. Hosmer, S. Lemeshow, & S. May. : Applied Survival Analysis: Regression Modeling of Time to Event Data

J. P. Klein & M. L. Moeschberger. : Survival Analysis : Techniques for Censored and Truncated Data

D. R. Cox & D. Oakes. : Analysis of Survival Data

J. D. Kalbfleisch & R. L. Prentiice. : The Statistical Analysis of Failure Time Data

R. G. Miller. : Survival Analysis

P. J. Smith. : Analysis of Failure and Survival Data

A. J. Gross & A. V. Clark. : Survival Distribution: Reliability Applications in the Biomedical Sciences

D. F. Moore. : Applied Survival Analysis Using R

*Bayesian Methods II*

Bayesian linear Model and Regression. Hierarchical and Empirical Bayes estimation. parametric empirical Bayes estimator and its computation. Bayesian computation and simulation: Markov Chain Monte Carlo (MCMC), Gibbs Sampling, Metropolis Hastings (MH) algorithm. Testing and Model selection.

References

P. M. Lee. : Bayesian statistics: An Introduction.
P. D. Hoff. : A First Course in Bayesian Statistical Methods
J.K. Ghosh, M. Delampady, & T. Samanta. : An Introduction to Bayesian Analysis: Theory and Methods
A. Gelman et al. : Bayesian Data Analysis
B. P. Carlin, & T. A. Louis. : Bayesian Methods for Data Analysis
C.P. Robert. : The Bayesian Choice
J.-M. Marin, & C.P. Robert. : Bayesian Core: A Practical Approach To Computational Bayesian Statistics
J.-M. Marin, & C.P. Robert. : Bayesian Essentials with R
J. Albrt. : Bayesian Computation with R

**Module II: Advanced Survey Sampling**

**Objective & Outcome**: Advanced survey sampling is an unique advanced survey course. It comprises of important features from classical and modern analytic methods used in survey sampling. This course is divided into two papers: Advanced Sample Survey and Model-dependent Inference in Survey Sampling. Some important features of this course are: (a) randomized response techniques; (b). small area estimation; (c) adaptive cluster sampling for rare populations; and (d) model-based and model-assisted estimators for efficient use of auxiliary information. The students are expected to learn the model-dependent modern survey techniques from a data analytic point of view. In Indian context there is great scope for applications of modern survey methodologies in different surveys (e.g., socio-economic surveys) conducted by public/private sectors. After completion of the course, students will be able to demonstrate their knowledge in various government organisations such as NSSO, CSO and also in non-government agencies. Small area estimation may be used for various national developments in different Government and private surveys and health related issues. Adaptive cluster sampling may be applied in forest surveys, estimation of rare birds, animals, soils etc. It may be used in different rare disease related health surveys as well.

*Advanced Sample Survey*

The basic model, Sampling Design and sampling schemes. Hanurav's unit drawing algorithm: Inclusion probabilities of first two orders, Relation with effective sample size and variance of effective sample size. Data and estimators-linear and linear unbiased estimators of population total, Horvitz –Thompson estimator, Generalized difference and generalized regression estimators, issues in non-negative variance estimation. $\pi$-PS sampling schemes of Midzuno-Sen, Brewer, Durbin and JNK Rao, Rao-Hartley-Cochran strategy. Randomised response: The Warner model: unbiased and maximum likelihood estimation. The unrelated question models methods (one and two unrelated characters)-unbiased estimation under the cases where the population in the unrelated group is known/unknown, comparison with the Warner model. Small Area Estimation - the basic estimation method, ratio and regression estimators for domains. Issues in small domain estimation - synthetic estimators. Adaptive sampling for rare and elusive population.

[25]

References

C. M. Cassel, E. Sarndal, & J. H. Wretman. : Foundations of Inference in survey Sampling.
A. Chaudhuri & H. Stenger. : Survey **S**ampling—Theory and Methods
A. Chaudhuri. : Essentials of Survey Sampling
A. Chaudhuri & J. W. E. Vos. : United Theory and Strategies of Survey Sampling
A. S. Hedayat & B. K. Sinha. : Design and Inference in Finite Population Sampling
P. Mukhopadhyay. : Inferential Problems in Survey Sampling
C. E. Sarndal, B. Swensson & J. Wretman. : Model assisted Survey Sampling
S. Thompson & G. Seber. : Adaptive Sampling

*Model-dependent Inference in Survey Sampling*

Inference under fixed population model: sufficiency and likelihood. Choosing good sampling strategy. Nonexistence theorem of Godambe and Joshi. Inference under super population model. Prediction approach. Asymptotic approach- asymptotic design unbiasedness and consistency. Finite population distribution function estimation : Chambers-Dunstan and Rao-Kovar-Mantel estimator. Resampling methods in finite population inferences (Only introduction). Bayesian Estimation in survey sampling –Empirical Bayes & Hierarchical Bayes estimators. Model based inference in small area estimation – Fay - Herriot model. [25]

References

C. M. Cassel, E. Sarndal, & J. H. Wretman. : Foundations of Inference in survey Sampling.
A. Chaudhuri & H. Stenger. : Survey **S**ampling—Theory and Methods
A. Chaudhuri. : Essentials of Survey Sampling
A. S. Hedayat & B. K. Sinha. : Design and Inference in Finite Population Sampling
E. Sarndal., B. Swensson & J. Wretman. : Model Assisted **S**urvey Sampling
W. Fuller. : Sampling Statistics
J. N. K. Rao. : Small Area Eatimation
P. Mukhopadhyay. : Topics in Survey Sampling
R. Chambers & R. Clark. : An Introduction to Model-Based Survey Sampling with Applicationns
R. L. Chambers & C. J. Skinner. : Analysis of Survey Data
R. L. Chambers et al. : Maximum Likelihood Estimation for Sample Survey
Z. Mashreghi et al. : A Survey of Bootstrap Method in Finite Population Sampling
J. Shao & D. Tu. : The Jackknife and Bootstrap

**Module II: Industrial Statistics**

**Objective & Outcome**: This elective course is specially designed for applications of statistics in **industry**. The course has two major areas in Industrial statistics, viz., Operations Research (OR) and optimizations. The course on OR will introduce students to implement quantitative methods and techniques for effective decisions–making; model formulation and applications that are used in solving business decision problems in **management engineering**. The course on Optimizations will introduce the theory of optimization methods and algorithms developed for solving various types of optimization problems in engineering and technology. After successful completion of the course, student will be able to: (a) identify and develop operational research models from the verbal description of the real system; and (b) understand the mathematical tools that are needed to solve optimization problems. This can be viewed as a **skill development** course.

*Operations Research*

Definition and Scope of Operations Research: phases in Operation Research, models and their solutions, decision-making under uncertainty and risk, use of different criteria, sensitivity analysis. Decision-making in the face of competition, two-person games, pure and mixed strategies, existence of solution and uniqueness of value in zero-sum games, finding solutions in mixed strategy games. Analytical structure of inventory problems, EOQ formula of Harris, its sensitivity analysis and extensions allowing quantity discounts and shortages.

Multi-item inventory subject to constraints. Models with random demand, the static risk model. P- and Q- systems with constant and random lead times.
Queuing models – specification and effectiveness measures. Steady-state solutions of M/M/1 and M/M/c models with associated distributions of queuelength and waiting time. M/G/1 queue and Pollazcek-Khinchine result. Network Flow Models, minimum spanning tree, shortest path, mincut-maxflow, CPM and PERT using network flow. Traveling salesman Problem. Replacement theory, sequencing. [25]

References


H. A. Taha. : Operational Research
F. S. Hillier & G. J. Leiberman. : Introduction to Operations Research
Kanti Swarup, P. K. Gupta & M. M. Singh. : Operations Research
D. T. Philips, A. Ravindran & J. Solberg. : Operations Research
C. W. Churchman, R. L. Ackoff & E. L .Arnoff. : Introduction to Operations Research
T. M. Starr & D. W. Miller. : Inventory Control - Theory & Practice
L. Kleinrock. : Queueing Systems
M. Sasieni, A. Yaspan & L. Friedman. : Operations Research
R. L. Ackoff. & M. W. Sasieni : Fundamentals of Operation Research.


*Optimization*

Generalized L.P.P. Bounded variables, decomposition principle of Dantizg and Wolfe. Transportation problem. Unconstrained Optimization, Optimality Conditions, first-order, second-order necessary sufficiency under convexity. Algorithms for Univariate Optimization: Bisection, Newton, Safeguarded Newton, Golden section search, Fibonacci rates of convergence. Integer programming – integer linear and mixed integer linear programming problems, Gomery's cutting plane method, Branch and Bound method. Binary Programming – Bala's algorithm ISI. Non-linear programming –optimization with equality & inequality constraints: Details of Karush-Kuhn-Tucker theory, Quadratic Programming – Wolfe's algorithm and Beale's algorithm. [25]

References


G. Hadley. : Non-linear and Dynamic Programming
K. G. Murthy. : Linear and Combinatorial Programming
P. Whittle. Optimization under Constraints - Theory and Applications of Non-linear Programming
S. S. Vajda. : Probabilistic Programming
N. S. Kambo. : Mathematical Programming Techniques
S. S. Rao. : Optimization - Theory and Applications
K. V. Mittal. : Optimization Methods

**Module III: Econometrics and Financial statistics**

**Objective & Outcome**: This course provides an introduction to some standard econometric methods and their applications; for example, simultaneous equations, panel data, introductory nonparametric and Bayesian econometrics, demand and production function analysis etc. The course emphasizes intuitive and conceptual understanding as well as hands on econometric analysis using modern computer software (like R) on data sets from economics and business. Students learn how to conduct empirical studies, as well as how to analyze and interpret results from other empirical works. Course on Statistics in Finance is a contemporary course in financial statistics. This course covers standard topics like option pricing, portfolio management and value-at-risk. After completion of this advanced course students may opt for research in econometrics and finance. Apart from that finance is one of the important areas where job opportunities are growing day by day

*Econometric Methods*

Single-equation linear model – some variations. Nonparametric methods in econometrics.
Simultaneous Equations – identification & estimation. Analysis of Panel Data. Bayesian Econometrics. Demand Analysis. Production Function Analysis. Analysis of some special econometric models. [25]

References

J. Johnston. : Econometric Methods
G. G. Judge, et.al. : The Theory and Practice of Econometrics
W. Greene. : Econometric Analysis
A. Zellner. : An Introduction to Bayesian Inference in Econometrics
E. Malinvaud. : Statistical Methods in Econometrics
H. Wold & L. Jureen. : Demand Analysis – a study in econometrics
P. Sankhayan. : An Intro.to the Economics of Agricultural Production
M. Nerlove. : Estimation and Identification of Cobb-Douglas Models
A. Pagan & A. Ullah. : Nonparametric Econometrics

*Statistics in Finance*

The value of time, Bond Pricing with a flat term structure, The term structure of interest rates and an object lesson,The Mean Variance Frontier, The global minimum variance portfolio, Efficient portfolio, The zero beta portfolio,Allowing for a riskless asset, Efficient sets with risk free assets, Pricing of futures contract,

Binomial option pricing, Multiperiod binomial pricing, Basic Option Pricing, the Black Scholes formula, Extending the Black Scholes formula, Dividends. Risk-free and risky assets. Contracts and options. Continuously compounded interest, present valuation, risk, risk-neutral valuation. Arbitrage: examples, contracts and options under no-arbitrage assumptions.
Option Pricing: Cox-Ross-Rubinstein Binomial and Black-Scholes models.
Elementary portfolio management, Value-at-risk. [25]

References

D. Ruppert. : Statistics and Finance
D. Reppert. : Statistics and Data Analysis for Financial Engendering
E. Lindstrom, H. Madsen & J. N. Nielsen. : Statistics for Finance
J. Franke, W. K. Hardle, & C. M. Hafner. : Statistics for Financial Markets
S. M. Ross. : Introduction to Mathematical Finance: Options and Other Topics
N. H. Bingham & R. Kiesel. : Risk-Neutral Val. : Pricing & Hedging of Financial Derivatives
V. S. Bawa, S. J. Brown, & R. W. Klein. : Estimation Risk and Optimal Portfolio Choice.
R. Carmona. : Statistical Analysis of Financial Data Using R.

# Course Revised Structure for Two Year M.Sc.
# In
# STATISTICS
# Department of Statistics
# West Bengal State University, Barasat.

[With effects from Academic year **2013-14**]

## Objective & Outcome

M. Sc. programme in statistics equips a graduate student to build a career in various disciplines; e.g., data sciences, health sciences, environmental sciences, medical research, pharmaceutical research, finance, public policy making, data analytics etc. In today's fast growing complex world Statistics becomes an important discipline both for researchers and job seekers. Students will learn an optimal blending of various statistical techniques and its' applications. These will help the students to acquire sufficient knowledge in Statistics so that the students can opt for an academic career or can prepare themselves for jobs in different private and public sectors. Moreover, this programme is structured in such a way that a B.Sc. student in Mathematics will be able to pursue it. After successful completion of the programme in Statistics, a student will:

1. have the versatility to work effectively in a broad range of analytic, scientific, government, financial, health, technical and other positions,
2. recognize the importance and value of statistical thinking, training, and approach to problem solving, on a diverse variety of disciplines,
3. be familiar with a variety of examples where statistics helps accurately explain abstract or physical phenomena,
4. be able to independently read statistical literature of various types, including survey articles, scholarly books, and online sources; and others,
5. be life-long learners who are able to independently expand their statistical expertise when needed, or for interest's sake.

## Information on the M.Sc. in Statistics Examination

- Conventionally a semester consists of 14 weeks and for a course carrying 1 Credit Point (CP), 14 lectures, each with one hour duration, is required.
- The 1000 Marks, 80 CP course has been divided into 18 theoretical (700 Marks, 56 CP) and 8 experimental (300 Marks, 24 CP) courses. Experimental sections include Practical, Assignments and Seminar.

- For each course, there will be an internal assessment based on a mid-semester examination carrying 20% of the total marks. However, the particulars of the examination (e.g. assessment and reassessment procedures), minimum qualifying marks for a course and for a semester will be in accordance with the existing university regulations.

## Courses Offered & Distribution of Marks

### Part 1, 1st Semester

| | | |
|---|---|---|
| Theoretical Courses | | 175 Marks, 14 CP |
| STA 501 | Mathematical Analysis | 50 Marks, 4 CP |
| STA502 | Statistical Inference I | 50 Marks, 4 CP |
| STA503 | Linear Models & Linear Algebra | 50 Marks, 4 CP |
| STA504 | Survey Methodologies | 25 Marks, 2 CP |
| Practical Courses | | 75 Marks, 6 CP |
| STA505 | Statistical Computing I | 25 Marks |
| STA506 | Practical I | 50 Marks |

Examination for STA 505 will be computer based on the topics covered in C and R and STA 506 comprises of computer & calculator based practical on the advanced topics related to STA 502-504.

### Part 1, 2nd Semester

| | | |
|---|---|---|
| Theoretical Courses | | 175 Marks, 14 CP |
| STA 511 | Probability Theory | 50 Marks, 4 CP |
| STA 512 | Statistical Inference II & Distribution Theory | 50 Marks, 4 CP |
| STA 513 | Regression Analysis | 50 Marks, 4 CP |
| STA 514 | Design of Experiments | 25 Marks, 2 CP |
| Practical Courses | | 75 Marks, 6 CP |
| STA515 | Statistical Computing II | 25 Marks |
| STA516 | Practical II | 50 Marks |

Examination for STA 515 will be computer based on the topics covered in C and R and STA 516 comprises of computer & calculator based practical on the advanced topics related to STA 512-514.

## Part 2, 1st Semester

| | | |
|---|---|---|
| Theoretical Courses | | 175 Marks, 14 CP |
| STA521 | Statistical Inference III | 50 Marks, 4 CP |
| STA522 | Stochastic Process | 50 Marks, 4 CP |
| STA523 | Time Series Analysis | 25 Marks, 2 CP |
| STA524 | Advanced Paper 1-Section I | 25 Marks, 2 CP |
| STA525 | Advanced Paper 2-Section I | 25 Marks, 2 CP |
| Practical Courses | | 75 Marks, 6 CP |
| STA526 | Statistical Computing III | 25 Marks |
| STA527 | Practical III | 50 Marks |

Examination for STA 526 will be computer based on the topics covered in C and R and STA 527 comprises of computer & calculator based practical on the advanced topics related to STA 521-525.

## Part 2, 2nd Semester

| | | |
|---|---|---|
| Theoretical Courses | | 175 Marks, 14 CP |
| STA 531 | Categorical Data Analysis & Advanced Topics | 50 Marks, 4 CP |
| STA 532 | Applied Multivariate Analysis | 50 Marks, 4 CP |
| STA 533 | Bayesian Methods | 25 Marks, 2 CP |
| STA 534 | Advanced Paper 1-Section II | 25 Marks, 2 CP |
| STA 535 | Advanced Paper 2-Section II | 25 Marks, 2 CP |
| Practical Courses | | 75 Marks, 6 CP |
| STA536 | Project Work | 50 Marks |
| STA537 | Practical III | 25 Marks |

Assessment for STA 536 will be based on seminar presentation, project report and the related viva-voce. Examination for STA 537 comprises of computer & calculator based practical on the advanced topics related to STA 531-535.

## Selection of the Advanced Papers

For the selection of advanced papers, students need to select any two of the following modules and the courses thereof. However, the modules, as well as the optional papers within each module, to be offered in a particular year, will be decided by the Department.

**Module1**: Life Data Analysis
Section I: Survival Analysis
Section II: Bayesian Methods II
**Module 2**: Advanced Survey Sampling
Section I: Advanced Survey Methodologies
Section II: Model-Based Inference in Survey Sampling
**Module 3**: Industrial Statistics
Section I: Operations Research
Section-II: Optimization
**Module 4**: Economic & Financial Statistics
Section I: Advanced Econometric Methods
Section II: Statistics in Finance

# Detailed Syllabus

## Part 1, 1st Semester

### STA 501: Mathematical Analysis

**Objective & Outcome**: This course is comprised of two important mathematical tools necessary for theoretical statistics. One is a foundation course on real analysis and another is an introductory course in complex analysis. This is prerequisite for understanding measure theoretic probability theory.

Group A (Real analysis)
Real number system, cluster points of sets, closed and open sets, compact sets, Bolzano-Weierstrass property and Heine-Borel property-statement & applications. [12] Sequence, series, convergence, real valued function, limit, continuity, uniform continuity, differentiability of univariate and multivariate functions, Mean value Theorems. [12]
Reimann integral, Reimann-Stieltjes integral,Review of sequence and series of functions, Uniform convergence: Term by term differentiation and integration, power series. [11]

Group B (Complex Methods)
Complex number system, Limit, Continuity and Differentiability, Analytic functions: Cauchy-Riemann equations, Power series, Complex integration. [15]

**References:**

T.M.Apostol :Mathematical Analysis.
W.Rudin :Principles of Mathematical Analysis.
R.R.Goldberg :Methods of Real Analysis.
J.C.Burkill :First Course of Mathematical Analysis.
J.C.Burkill & H.Burkill :Second Course of Mathematical Analysis
A. Ahlfors : Complex Analysis.

**STA 502: Statistical Inference I**

**Objective & Outcome**: The Statistical Inference I will provide basic ideas of inference from data; in particular, detail theory for point estimation. Fixed sample and sequential Testing problems will be introduced. In Decision theory classical inference problems are viewed as a risk minimization problem and optimum rules are evaluated. This is a fundamental theoretical statistics course.

Data Reduction: Sufficiency and Minimal sufficiency, Completeness, Bounded completeness and Ancillary Statistic, Exponential family of distributions. [8]
Point Estimation: Bhattacharya system of lower bounds, Minimum Variance Unbiased Estimators- Rao-Blackwell & Lehmann-Scheffe Theorems. [7]
Testing of Hypothesis I: Nonrandomized and Randomized tests, critical function, power function. Most Powerful (MP) Tests-Neyman-Pearson Lemma (Existence, Sufficiency and Necessity). UMP tests: Simple problems for Exponential and Pitman families of distributions. Enlargement technique for testing a composite null against a composite alternative. [14]
Sequential Analysis: Sequential Probability Ratio test, Termination of SPRT, Wald's equation of ASN, Optimality of SPRT, Wald's fundamental identity-OC functions, SPRT for one sided hypotheses. [14]
Decision Theory: Loss, Decision rules and Risk function, Admissibility of decision rules, Bayes and Minimax rules. [7]

**References :**


| | |
|---|---|
| C.R.Rao | :Linear Statistical Inference and its Applications. |
| T.W.Anderson | :Introduction to Multivariate Analysis. |
| A.M.Khirsagar | :Multivariate Analysis. |
| S.S.Wilks | :Mathematical Statistics. |
| M.S.Srivastava & C.G.Khatri | :Introduction to Multivariate Statistics. |
| E.L.Lehmann | :Testing Statistical Hypotheses. |
| S.Zacks | :The Theory of Statistical Inference. |
| E.L.Lehmann | :Theory of Point Estimation. |
| T.S.Ferguson | :Mathematical Statistics. |
| Nitis Mukhopadhyay | Probability and Statistical Inference. |


**STA 503: Linear Models & Linear Algebra**

**Objective & Outcome**: An introductory course in linear algebra with emphasis on matrix algebra will be taught here. This is a prerequisite course for linear models. In Linear Models students will learn detailed theoretical development for Gauss-Markov models and related inferences and extensions; and its applications in regression problems. This is theoretical coursr.

Group A (Linear Models)
Gauss-Markov model: Estimable functions, BLUE & Gauss Markov Theorem, Estimation space and Error space, Sum of squares due to a set of linear functions, Estimation with correlated observations , Least Square estimation with linear restriction on the parameters. [15]
General linear hypothesis: F test for general linear hypothesis and associated confidence sets, Multiple comparison procedures of Scheffe and Tukey, Applications of general linear hypothesis to regression, analysis of variance and covariance. [12]
Random and Mixed effects models (balanced case): Estimation of variance components. [8]

Group B (Linear Algebra)
Review of Vector space and Matrix Algebra, Singular values and Singular value decomposition, Jordan decomposition. Idempotent matrices and their properties. Generalised Inverse of matrices: Definition and properties, Different techniques of obtaining generalised inverse, Reflexive generalised inverse-Moore Penrose generalised inverse, Moore Penrose generalised inverse using Singular Value Decomposition. Extrema of Quadratic forms and eigenvalues. [15]

**References :**

H.Scheffe Analysis of Variance. :
S.R.Searle :Linear Models.
G.A.F.Seber :Linear Regression Analysis.
N.Giri :Analysis of Variance.
D.D.Joshi :Linear Estimation & Design of Experiments.
C.R.Rao : Linear Statistical Inference and its Applications.

**STA 504: Survey Methodologies**

**Objective & Outcome**: In Survey Methodologies students can learn the basic concepts of finite populations, drawing of samples by different sampling techniques from the populations, and related estimation of target quantities (that is, finite population parameters) like population mean, variances etc. Classical survey mythologies taught here will help students to understand how surveys are conducted in different public and private sectors.

Probability sampling from a finite population. [2]

Basic sampling schemes –Unequal probability sampling with and without replacement, Related estimators of population total/mean, their variances and variance estimators – Mean per distinct unit in simple random with replacement sampling, Hansen Hurvitz estimator in unequal probability sampling with replacement, Des Raj and Murthy’s estimator (for sample of size two) in unequal probability sampling without replacement. [7]
Stratified sampling – The allocation scheme & the basic idea of optimal allocation, construction of strata. [3]

Basic ideas of Ratio, Product, Difference and Regression estimators. Unbiased Ratio type estimators. Hartley – Ross estimator in simple random sampling. [3]
Sampling and sub-sampling of clusters. Two-stage sampling with equal/unequal number of second stage units and simple random sampling without replacement / unequal probability sampling with replacement at first stage. [6]
Double sampling for stratification. Double sampling ratio and regression estimators. [4]

**References :**


W.G.Cochran :Sampling Techniques.

Des Raj & Chandak :Sampling Theory.

A.S.Hedayat & B.K.Sinha :Design & inference in finite population sampling.

P.Mukhopadhyay :Theory & Methods of Survey Sampling.


**STA 505: Statistical Computing I**

**Objective & Outcome**: Introduction to classical C & modern R programming will be taught here. Programming is an integral part statistics in modern days since it helps to apply statistical theories in complex real world.

Computing with C
A brief overview of C: Syntax, loops, pointers, arrays, structures, functions, files.
Review of statistical programming in C.

Computing with R
Basic operations: Basic arithmetic operations (addition, subtraction, multiplication, division etc): Use of R as a scientific calculator.
Graphical display: Stem-leaf plot, Histogram and Density plot, Box plot, Scatter plot.
Descriptive statistics: Simple Descriptive Measures (mean, variance, sum of squares, maximum, minimum, quantiles, correlation coefficient ).
Sample drawing techniques: Drawing of random numbers, SRS procedure-with and without replacements.
Matrix Calculations: **V**ectors and matrices: Basic operations on vector and matrices (addition, multiplication, calculation of quadratic forms).
Determinant, Trace, Rank, Inverse and Solution of linear equations.
Eigenvalues and Eigenvectors of a square symmetric matrix. Spectral Decomposition, Choleski Decomposition, Singular Value Decomposition of any matrix and rank determination. Moore-Penrose Generalized inverse using Singular Value Decomposition**.**

**References :**


Kernighan and Ritchie : The **C** Programming Language.

Hrishikesh Kanitkar Let us C.

W. N. Venables and B. D. Ripley : Modern Applied Statistics with S.

Michael J. Crawley Statistics: An introduction using R.

**STA 506: Practical I**

**Objective & Outcome**: In these courses practical necessary practical exercises related to theoretical courses taught and this course will help students to learn implementations of important statistical tools in real life data sets.
Computer & calculator based applications of the advanced topics related to STA 502-504.

## Part 1, 2nd Semester

**STA 511: Probability Theory**

**Objective & Outcome**: Here rigorous measure theoretic probability theory will be taught. This course will help students in depth understanding of theoretical statistics. Specially, comprehensive understanding the large sample theories of statistics are heavily depend on this course.

Borel fields & Sigma fields in probability, Probability as a measure, Measurable functions: Random variable as a measurable function.
Integration of a measurable function with respect to a measure.
Sequence of measurable functions: Monotone convergence theorem, Fatou's lemma and Dominated convergence theorem and their probabilistic aspects, Radon-Nikodym theorem (statement and use). [15]
Distribution functions: Application of Lebesgue-Stieltje's measure, Expectation, Generating functions and Characteristic function, Inversion theorem and Continuity Theorem (only statement). Independence-Borel Cantelli Lemma. [15]
Sequence of random variables, Different modes of convergence of a sequence of random variables--Inter-relations, Weak and Strong laws of large numbers-Kolmogorov's inequality [12]
Central limit Theorem for iid random variables, CLT for a sequence of random variables (statement only). [8]

**References :**


| | | |
|---|---|---|
| A.K.Basu | : | Measure theory and Probability. |
| B.R.Bhat | : | Modern Probability Theory. |
| P.Billingsley | : | Probability and Measure. |
| J.F.C. Kingman & S.J.Taylor | : | Introduction to Measure and Probability. |
| R.G.Laha & V.K.Rohatgi | : | Probability theory. |
| R. Ash | : | Real Analysis and Probability. |


**STA 512: Statistical Inference II & Distribution Theory**

**Objective & Outcome:** Statistical Inference II will impart students the further theory of statistical hypothesis testing and confidence interval estimation. The testing problems have immense applications in different fields. In Sampling Distribution II students get familiar with the concepts of multivariate normal distribution and the sampling distributions of some standard statistics under multivariate normal populations.

Group A (Statistical Inference II)

Testing of Hypothesis II: UMP tests for Monotone Likelihood Ratio (MLR) families. Generalised Neyman-Pearson Lemma-UMPU tests for one parameter families, Locally best tests. Similar tests, Neyman structure, UMPU tests for composite hypotheses-nuisance parameters, Behrens-Fisher Problem. [20]

Confidence Interval Estimation: Relation with hypothesis testing, Optimum parametric confidence intervals. [5]

Group B (Distribution Theory)

Non central distributions: $\chi^2$, t and F. [5]

General discussion on Multivariate distributions- Multivariate Normal Distribution, Distribution of Quadratic Forms-Cochran's Theorem. [7]

Random sampling from a Multivariate normal distribution: Wishart matrix-its distribution (without derivation) and properties, Hotelling $T^2$ and Mahalanobis $D^2$ statistics. [13]

**References :**


| | | |
|---|---|---|
| C.R.Rao | : | Linear Statistical Inference and its Applications. |
| E.L.Lehmann | : | Theory of Point Estimation. |
| T.W.Anderson | : | Introduction to Multivariate Analysis. |
| A.M.Khirsagar | : | Multivariate Analysis. |
| S.S.Wilks | : | Mathematical Statistics. |
| M.S.Srivastava & C.G.Khatri | : | Introduction to Multivariate Statistics. |
| R.J.Muirhead | : | Aspects of Multivariate Statistical Theory. |


**STA 513: Regression Analysis**

**Objective & Outcome:** This is a comprehensive course in regression. Regression Analysis consists of theoretical developments for inferences under deviations from Gauss-Markov models. Here concepts of outliers and robust regression will be introduced to students. Students will be able to investigate validity of the regression models in practical situations. Here students will learn to develop nonlinear regression when responses are binary or count in nature (GLM regression). Students will learn to implement regressions for continuous and discrete responses.

Univariate and Bivariate data: Concept of Regression.

Regression with one explanatory variable: Direct, Reverse, Orthogonal and Least Absolute Deviation (LAD) regressions with applications, Weighted Least Squares technique.

Regression with several explanatory variables: Multiple linear regressions. [5]

Residual analysis: Residuals and their plots: Tests of fit of a model, Detection of

Outliers. [9]
Departures from the usual assumptions: Heteroscedasticity, Autocorrelation, Multicollinearity, Non-normality- Detection and remedies, Robust regression. [15]
Model Selection and non linear models. [6]
Generalized Linear Models: Introduction, Components, Goodness of fit measures-residuals and deviance. Inference for Generalized Linear Models. Applications to binary, count and polytomous data, Over dispersion. Marginal, Conditional and quasi likelihood functions (simple ideas). [15]

**References :**

H.Scheffe : The Analysis of Variance.
S.R.Searle : Linear Models.
G.A.F.Seber : Linear Regression Analysis.
N.Giri : Analysis of Variance.
D.D.Joshi : Linear Estimation & Design of Experiments.
Chatterjee & Hadi Sensitivity analysis in linear regression.
Chatterjee & Price :Regression analysis by example.

**STA 514: Design of Experiments**

**Objective & Outcome:** In this course students will be taught the concepts of controlled experiments and related inference problems. It has enormous applications in designs and analysis of experiments in the physical, chemical, biological, medical, social, psychological, economic, engineering, agricultural, or industrial sciences. The course will examine how to design experiments, carry them out, and analyze the data they yield. Upon completion, students will be able to understand the issues and principles of Design of experiments.

Basic principles of design, Elimination of heterogeneity in one and two directions.
General Block designs and its information matrix(C), Concepts of Connectedness, Orthogonallity and Balance,
Intrablock analysis of orthogonal (CRD, RBD, LSD) and non-orthogonal (Balanced Incomplete Block (BIB) and Youden Square(YS)) designs.
Recovery of interblock information in BIB design
Construction of complete classes of Mutually Orthogonal Latin Squares ( MOLS);
Construction of BIBD using MOLS and Boses's fundamental method of difference.
Factorial experiment: Confounding and balancing in symmetric factorial experiments- Analysis. [25]

**References :**

M.C.Chakraborty : Mathematics of Design and Analysis of Experiments.
A.Dey : Theory of Block Designs.
D.Raghavarao : Constructions & Combinatorial Problems in Design of Experime
R.C.Bose : Mathematical Theory of Symmetric Factorial

| | | |
|---|---|---|
| | | (Sankhya - Vol. 8). |
| R.C.Bose | : | On the Construction of Balanced Incomplete Block I (Annals Eugenics - Vol. 9). |
| D.C.Montogomery | : | Design and Analysis of Experiments. |

**STA 515: Statistical Computing II**

**Objective & Outcome:** This a continuation of computing course in Semester 1. Simulations will be taught in C programming; while in R, data manipulation, statistical distributions, regressions will be taught using R functions.

Computing in C
Stochastic simulation: Generation of Random Numbers and selection of samples, Monte Carlo Simulation.

Computing with R
Data Manipulation: Built-in datasets in R, read.table() and write.table() functions, Reading from a text file.
The built-in distributions in R : cdf, densities, quantiles, random samples.
Statistical Inference: One sample and two sample problems, Analysis of Variance, Goodness of fit tests.
Regression Analysis**:** Multiple linear regression (lm()) function : model specification and fitting, computing predicted values and residuals, inference. Weighted Least Squares. Measures of identifying unusual observations( influence.measures(), dfbetas(), dffits(), cook.distance()). Box-Cox Transformation, Q-Q plot, Shapiro-Wilk Test.

**STA 516: Practical II**

**Objective & Outcome**: In these courses practical necessary practical exercises related to theoretical courses taught and this course will help students to learn implementations of important statistical tools in real life data sets.

Computer & calculator based applications of the advanced topics related to STA 512-514.

**Part 2, 1st Semester**

**STA 521: Statistical Inference III**

**Objective & Outcome**: In the first part of this statistical inference course students will learn classical frequentist approach for parametric inference based on approximate distributions of the statistics in large samples. This enables students to draw inference based on statistics whose exact sampling distributions are very difficult to evaluate analytically. This course is an important prerequisite for learning advanced data analysis. In the second part of the course students will learn to draw distribution-free nonparametric inference in classical testing problems along with an introductory discussion on nonparametric density estimation problem.

Group A (Asymptotic Methods)
Large sample properties of estimators: Consistency, Efficiency and Asymptotic Normality-CAN and BAN estimators. [10]
Maximum likelihood method of estimation- Large sample properties. [10]
Likelihood ratio, Rao and Wald tests for simple and composite hypotheses- properties and asymptotic distribution of test criteria in the simple hypothesis case. [5]

Group B (Nonparametric Methods)
U-statistics- Definition and Asymptotic properties.
Nonparametric tests: Single sample Problems: Location, Location-cum-symmetry, and Goodness-of-fit problems.
Two-sample Problems: Location, Scale and Homogeneity problems.
Multi-sample location problem.
Friedman Two-way Analysis of variance problem.
Bivariate association problem, Cochran Q-test for dependent samples.
Nonparametric Interval Estimation.
Nonparametric Density Estimation
Concept of Asymptotic Relative Efficiency. [25]

**References :**


J.D.Gibbons :Nonparametric Inference.

T.P. Hettmansperg:Statistical Inference based on ranks.

C.R.Rao :Linear Statistical Inference and its Applications.

E.L.Lehmann :Theory of Point Estimation.

R.J.Serfling :Approximation Theorems of Mathematical Statistics.

E.L.Lehmann :Large Sample Theory.


**STA 522: Stochastic Processes**

**Objective & Outcome**: Here theory of different dependent processes will be taught to students. These processes are developed to model real life random phenomena from various fields of sciences and social sciences where underlying random variables are dependent in nature.

Markov chain with finite state space and countable state space, Classification of states, Chapman-Kolmogorov equation, Calculation of n-step transition probability matrix and its limit, Stationary distribution of Markov chain, Random walk and Gambler’s ruin problem, Reversibility. [16]

Discrete state space continuous time Markov chains, Poisson process, Pure birth process, Pure death process, Birth and death processes. [12]
Renewal theory: Elementary Renewal theorem, Stopping time, Statement and uses of Key Renewal theorem. [12]
Branching Process: Galton Watson branching process, Probability of ultimate extinction, Distribution of Population size. [6]
Continuous process: Brownian motion. [4]

**References :**

S.Karlin and H.M.Taylor :A First Course in Stochastic Processes.
J Medhi :Stochastic Process.
D.R.Cox :Renewal Theory.
S.Ross :Stochastic Process.
Basu A.K. :Stochastic Process.
Hoel P.G., Port S.C. and Stone C.J :An Introduction to Stochastic Process.

**STA 523: Time Series Analysis**

**Objective & Outcome**: In Time Series course students will experience introductory theoretical developments for particular type of dependency, known as time dependency. Primarily stationary time series will be taught here. Applications of time series data are in abundant in reality. In particular, for learning financial statistics time series analysis is necessary introductory course.

Stationary Time Series, linear process, causality and Invertibility, properties of linear stationary process, autocovariance function (ACVF) and partial autocorrelation function (PACF), methods of finding ACVF, ARMA process as particular case. [10]
Forecasting a time series, Best linear unbiased predictor, Iterative methods (Durbin - Levinson and Innovations Algorithm) of finding predictor with ARMA process as a particular case. [8]
Periodogram, Spectral densities of some standard processes, Estimation of spectrum. [7]

**References :** :

C.Chatfield :The Analysis of Time Series - An Introduction.
G.E.P.Box, G.M.Jenkins & G.C.Reinsel :Time Series Analysis - Forecasting and Control.
A.Pankratz :Forecasting with Univariate Box-Jenkins Model.
G. Jancek and L. Swift :Time Series - Forecasting, Simulation, Applications.

**STA 524: Advanced Paper 1 (Section I)**
**STA 525: Advanced Paper 2 (Section I)**

### STA 526: Statistical Computing III

**Objective & Outcome**: This is a continuation of computing courses in M.Sc. Part I. Numerical methods and programming will be taught C and R programming. This course will be very handy for project work in final semester.

Advanced Computing with C

Numerical methods (Iteration, Newton-Raphson, Quasi-Newton algorithms) with C.

Advanced Computing with R

Creating user defined functions**:** Conditional statements, loops, arrays.

Numerical optimization**:** Solution of numerical equations (single unknown)-

Maximum Likelihood Estimates, Nonlinear regression(nls() and nlm() functions).

Numerical Integration**:** Numerical evaluation of probabilities involving one and two random variables.

Simulation: Simulating functions of random variables.

### STA 527: Practical III

**Objective & Outcome**: In these courses practical necessary practical exercises related to theoretical courses taught and this course will help students to learn implementations of important statistical tools in real life data sets.

Computer & calculator based applications of the advanced topics related to \ STA 521-525.

## Part 2, 2nd Semester

### STA 531: Categorical Data Analysis & Advanced Topics

**Objective & Outcome**: Analysis of Contingency tables and regressions for ordinal/nominal responses will be taught here. Advanced data analysis course comprises of three different topics. The first topic will introduce students how to build models for a non-cross-sectional type data called longitudinal or panel data. In other two topics, Missing Data Mechanism and Re-Sampling Techniques, students will learn two very practical techniques in Statistics. Missing data is a part of all most all real life surveys. Students will learn how to use missing data sets efficiently for estimation problems. In modern era of high level extensive computing, Re-sampling methods for drawing inference, particularly bootstrap, becomes extremely popular in practice since its implementation does not require theoretical knowledge of statistics. Here students will learn basic theoretical understanding of re-sampling theory and its implementations. In view of above facts this course can be viewed as a **skill development** course in Statistics.

Group A( Categorical Data Analysis)

Categorical Response Data: Nominal/ Ordinal Distinction, Probability Distributions for Categorical Data-Binomial& Multinomial Distributions.
Inference for a proportion: Wald, Score, and Likelihood-Ratio Inference for Binomial Parameter.

Contingency Tables**:** Probability Structure for Contingency Tables: Joint, Marginal, and Conditional Probabilities, Relative risk and odds ratio-properties.
Measures of association and tests for independence in contingency tables: Nominal-Nominal, Ordinal – Ordinal and Nominal–Ordinal Tables.
Exact Inference for Small Samples- Fisher's Exact Test for 2 × 2 Tables.
Association in more than two-way classified data: Partial association, Conditional Versus Marginal Associations- Simpson's Paradox, Conditional and Marginal Odds, log-odds ratio and its distribution, Independence-Conditional Versus Marginal. [20]

Group B (Advanced Data Analysis Techniques)
Longitudinal Data- Introduction with motivation, Exploring longitudinal Data with some specific dependence structure. [5]
Missing data mechanism**-**Inference procedures for data with missing values- E-M algorithms. [7]
Re-sampling Techniques- Introduction to Jackknife and Bootstrap – methods for estimating bias ,standard error and distribution function based on i.i.d. random variables. Standard examples. Justification of the methods in i.i.d. set-up, Bootstrap confidence intervals, Computational aspects . [15]

**References :**


A.Agresti : Categorical Data Analysis.
P.McCullagh & N.Nelder : Generalized Linear Models.
R.J.A Little and D.B.Rubin : Statistical analysis with Missing data.
B. Efron : The Jackknife, the Bootstrap and other Sampling Plans.
B.Efron : Bootstrap methods - another look at jackknife.
B.Efron & R.J.Tibshirani : An Introduction to the Bootstrap.
J.Shao & D.Tu : The Jackknife and Bootstrap.
Zvi Bodie, Alex Kane & Alan J Marcus. : Investments.
Richard A Brealey & Stewart C Myers. : Principles of Corporate Finance.


**STA 532: Applied Multivariate Analysis**

**Objective & Outcome**: This is extremely useful course consists of important multivariate real life problems like multivariate regressions, ANOVA, AMCOVA, principal components analysis, classification and discrimination problems, factor analysis and cluster analysis. In practice survey data are generally multivariate in nature and these techniques will help students to perform exploratory data analysis to survey data to revel important conclusions about the underlying populations. These techniques are very common in any field where data based conclusions are to be drawn; particularly in Analytics. This course develops important **skills** to handle multivariate problems.

Multivariate linear regression model: estimation of parameters, tests of linear hypotheses, different test criteria, Multivariate Analysis of variance of one and two way classified data. Multivariate Analysis of Covariance. [15]
Hierarchical and non-hierarchical clustering methods. [8]
Classification and discrimination procedures for discrimination between two known populations – Bayes, Minimax and Likelihood Ratio procedures. Discrimination between two multivariate normal populations. Sample discriminant function. Likelihood ratio rule. Tests associated with discriminant function, Probabilities of misclassification and their estimation. Classification of several populations. Fisher's method for discriminating among several populations. [10]

Population and sample principal components and their uses and related large sample inference. [5]
The orthogonal factor model, Estimation of factor loading, Factor rotation, Estimation of Factor scores, Interpretation of Factor Analysis. [7]
Canonical variables and canonical correlations (population & sample) and their interpretations. Large sample inferences. [5]

**References :**

T.W.Anderson : An Introduction to Multivariate Statistical Analysis.
R.J.Muirhead : Aspects of Multivariate Statistical Theory.
G.A.F.Seber : Multivariate Observations.

**STA 533: Bayesian Methods**

**Objective & Outcome**: The course will impart introductory idea of Bayesian methods. Bayesian methods will introduce basic ideas of another kind of statistical theory for inference on complex random phenomena.

Overview and comparison of different paradigms, Relative advantages and disadvantages. Priors & Posteriors : Subjective priors, Conjugate and other Non-subjective priors. [10]
Bayesian Inference – estimation, testing, interval estimation and prediction for some common models and common priors.
Hierarchical and Empirical Bayes Methods. Bayesian Computation. [15]

**References :**

J.O.Berger : Statistical Decision Theory and Bayesian

Analysis. C.P.Robert : The Bayesian Choice.

P.McCullagh & A.J.Nelder : Generalized Linear Models.

**STA 534: Advanced Paper 1(Section –II)**
**STA 535: Advanced Paper 2 (Section-II)**

**STA 536: Project Work**

**Objective and Outcome**: Students will independently solve theoretical/ empirical statistical problems.

**STA 53 : Practical IV**

**Objective & Outcome**: In these courses practical necessary practical exercises related to theoretical courses taught and this course will help students to learn implementations of important statistical tools in real life data sets.

Computer & calculator based applications of the advanced topics related to STA 531-535.

## Advanced Papers

**Module 1: Life Data Analysis**

**Objective & Outcome**: This module is partially helpful for students who are interested in **Biostatistics or Medical Statistics**. The Survival Analysis course will focus on basic concepts of survival (time-to-event) data analysis. Some of the important features that students are expected to learn in this course are: (a) understanding of different types of censoring, and learn to estimate and interpret survival characteristics; (b) assess the relationship of risk factors and survival times using the Cox regression model, and assess the appropriateness and adequacy of the model; and (c) development of analytic skills through the analysis of data sets taken from the fields of medicine and public health. Another topic in this course is Bayesian Methods II. In this course student will learn Bayesian linear and no nonlinear regressions, Bayesian estimation and testing problems and Bayesian computation & simulations (MCMC, Gibbs sampling and MH algorithm). This course in Bayesian inference will enable students to perform Bayesian data analysis in many real life complex problems. Students will learn Bayesian computing using Win Bug.

**Section I: Survival Analysis**

Concepts of lifetime, Various schemes of censoring and associated likelihoods. [4]

Estimation of survival function:

Parametric procedure: Point estimation, Scores and likelihood ratio tests for selected parametric models and confidence intervals. [5]

Distribution free procedures: Actuarial estimator, Kaplan-Meier and Nelson – Aalen estimators. [7]

Regression models: Estimation in parametric and Semi-parametric models-Cox's proportional hazard model, Time dependent covariates, Rank test. [6]
Competing risk analysis and Multivariate models. [3]

**References :**

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|---|---|
| D.R.Cox & D.Oakes | :Analysis of Survival Data. |
| A.J.Gross & A.V.Clark | :Survival Distribution: Reliability Applications in the Biomedical Sciences. |
| R.G.Miller | :Survival Analysis. |
| P.J.Smith | :Analysis of Failure and Survival Data. |
| J.D.Kalbfleisch & R.L.Prentiice | :The Statistical Analysis of Failure Time Data. |

**Section II: Bayesian Methods II**

Bayesian linear Model and Regression . [4]
Non-linear model---Logit model, Introduction to GLM . [3]
Bayesian Inference—Point estimation and Interval estimation, Hypothesis testing and Bayes factors . [5]
The Empirical Bayes (EB) approach—Nonparametric EB point estimation, Parametric EB point estimation . [4]
Bayesian Computation and Simulation--- Markov chain Monte Carlo (MCMC: Gibbs sampling), Metropolis Hastings algorithm (MH) . [5]
Model selection . [ 2]
Win bug. [ 2]

**References :**

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| P.M.Lee, Arnold | Bayesian Statistics: An Introduction, Arnold. |
| A. Gelman, J. B. Carlin, Stern and D. B. Rubin | Bayesian Data Analysis, Chapman Hal.l |
| B. P. Carlin, T. A. Louis | Bayesian methods for Data Analysis. |
| B. P. Carlin, T. A. Louis | Bayes and Empirical Bayes Methods for Data Analysis. |
| J.K. Ghosh, M. Delampady, T. Samanta | An Introduction to Bayesian Analysis: Theory and Methods. |
| D. Lunn, C. Jackson, N. Best, A. Thomas and D. Spiegelhalter | The BUGS Book - A Practical Introduction to Bayesian .Analysis |
| I. Ntzoufras | Bayesian Modelling using WINBUGS. |

**Module 2: Advanced Survey Sampling**

**Objective & Outcome**: Advanced survey sampling is an unique advanced survey course. It comprises of important features from classical and modern analytic methods used in survey sampling. This course is divided into two papers: Advanced Sample Survey and Model-dependent Inference in Survey Sampling. Some important features of this course are: (a) randomized response techniques; (b). small area estimation; (c) adaptive cluster sampling for rare populations; and (d) model-based and model-assisted estimators for efficient use of auxiliary information. The students are expected to learn the model-dependent modern survey techniques from a data analytic point of view. In Indian context there is great scope for applications of modern survey methodologies in different surveys (e.g., socio-economic surveys) conducted by public/private sectors. After completion of the course, students will be able to demonstrate their knowledge in various government organisations such as NSSO, CSO and also in non-government agencies. Small area estimation may be used for various national developments in different Government and private surveys and health related issues. Adaptive cluster sampling may be applied in forest surveys, estimation of rare birds, animals, soils etc. It may be used in different rare disease related health surveys as well.

**Section I: Advanced Survey Methodologies**

The basic model, Sampling Design and sampling schemes. Hanurav's unit drawing algorithm: Inclusion probabilities of first two orders, Relation with effective sample size and variance of effective sample size. [4]

Data and estimators-linear and linear unbiased estimators of population total, Horvitz –Thompson estimator, Generalized difference and generalized regression estimators, issues in non-negative variance estimation. $\pi$ PS sampling schemes of Midzuno-Sen, Brewer, Durbin and JNK Rao, Rao-Hartley-Cochran strategy. [5]

Randomised response: The Warner model: unbiased and maximum likelihood estimation. The unrelated question models methods (one and two unrelated characters)-unbiased estimation under the cases where the population in the unrelated group is known/unknown, comparison with the Warner model. [5]

Small Area Estimation - the basic estimation method, ratio and regression estimators for domains. Issues in small domain estimation - synthetic estimators. [3]

Non-sampling errors and biased responses, errors in surveys, modeling observational errors, estimation of variance components, application to longitudinal studies (repetitive surveys). [4]

Adaptive sampling for rare and elusive population . [4]

**References :**


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|---|---|
| C.M.Cassel,.E.Sarndal& J.H.Wretman. | :Foundations of Inference in survey Sampling. |
| A.Chaudhuri & H.Stenger | :Survey **S**ampling—Theory and Methods. |
| A.Chaudhuri | : Essentials of Survey Sampling. |
| A.Chaudhuri & J.W.E.Vos | :United Theory and Strategies of Survey Sampling. |
| A.S.Hedayat & B.K.Sinha | :Design and Inference in Finite Population Sampling. |
| P.Mukhopadhyay | :Inferential Problems in Survey Sampling. |
| C.E.Sarndal.,B.Swensson& | :Model assisted Survey Sampling. |

J.Wretman
S. Thompson & G. Seber Adaptive Sampling.

**Section II: Model-Based Inference in Survey Sampling**

Inference under fixed population model: sufficiency and likelihood [1]
Choosing good sampling strategy [1]
Nonexistence theorem of Godambe and Joshi [3]
Inference under super population model [4]
Prediction approach [4]
Asymptotic approach- asymptotic design unbiasedness and consistency [2]
Model based inference in small area estimation – Fay - Herriot model [4]
Bayesian Estimation in survey sampling –Empirical Bayes & Hierarchical Bayes estimators [3]
Estimation of Distribution Function [3]

**References :**


C.M.Cassel, C.E.Sarndal.& J.H.Wretman : Foundations of Inference in **S**urvey Sampling.
A.Chaudhuri & H.Stenger : Survey **S**ampling—Theory and Methods
A.Chaudhuri Essentials of Survey Sampling.
A.S.Hedayat & B.K.Sinha : Design and Inference in Finite Population Sampling.
C.E.Sarndal., B.Swensson& J.Wretman : Model Assisted **S**urvey Sampling.
J.N.K.Rao Small **A**rea Estimation.
M. Ghosh & G.Meeden Bayesian Methods for finite Population Sampling.


**Module 3: Industrial Statistics**

**Objective & Outcome**: This elective course is specially designed for applications of statistics in **industry**. The course has two major areas in Industrial statistics, viz., Operations Research (OR) and optimizations. The course on OR will introduce students to implement quantitative methods and techniques for effective decisions–making; model formulation and applications that are used in solving business decision problems in **management engineering**. The course on Optimizations will introduce the theory of optimization methods and algorithms developed for solving various types of optimization problems in engineering and technology. After successful completion of the course, student will be able to: (a) identify and develop operational research models from the verbal description of the real system; and (b) understand the mathematical tools that are needed to solve optimization problems. This can be viewed as a **skill development** course.

**Section I: Operations Research**

Definition and Scope of Operations Research: phases in Operation Research, models and their solutions, decision-making under uncertainty and risk, use of different criteria, sensitivity analysis.

Decision-making in the face of competition, two-person games, pure and mixed strategies, existence of solution and uniqueness of value in zero-sum games, finding solutions in mixed strategy games.
Analytical structure of inventory problems, EOQ formula of Harris, its sensitivity analysis and extensions allowing quantity discounts and shortages. Multi-item inventory subject to constraints. Models with random demand, the static risk model. P- and Q- systems with constant and random lead times.
Queuing models – specification and effectiveness measures. Steady-state solutions of M/M/1 and M/M/c models with associated distributions of queuelength and waiting time. M/G/1 queue and Pollazcek-Khinchine result.
Network Flow Models, minimum spanning tree, shortest path, mincut-maxflow, CPM and PERT using network flow. Traveling salesman Problem.
Replacement theory, sequencing. [25]

**References :**


| | | |
|---|---|---|
| H.A.Taha | : | Operational Research. |
| F.S.Hillier & G.J.Leiberman | : | Introduction to Operations Research. |
| Kanti Swarup, P.K.Gupta & M.M.Singh | : | Operations Research. |
| D.T.Philips, A.Ravindran & J.Solberg | : | Operations Research. |
| C.W.Churchman, R.L.Ackoff & E.L.Arnoff | : | Introduction to Operations Research. |
| T.M.Starr & D.W. Miller | : | Inventory Control – Theory & Practice |
| .L.Kleinrock | : | Queueing Systems. |
| Sasieni,Yaspan & Friedman | : | Operations Research. |
| Sasieni & Achoff | : | Operations Research. |


**Section II: Optimization**

Generalized L.P.P. Bounded variables, decomposition principle of Dantizg and Wolfe. Transportation problem.
Unconstrained Optimization, Optimality Conditions, first-order, second-order necessary sufficiency under convexity. Algorithms for Univariate Optimization: Bisection, Newton, Safeguarded Newton, Golden section search, Fibonacci rates of convergence.
Integer programming – integer linear and mixed integer linear programming problems, Gomery's cutting plane method, Branch and Bound method. Binary Programming – Bala's algorithm ISI.
Non-linear programming –optimization with equality & inequality constraints: Details of Karush-Kuhn-Tucker theory, Quadratic Programming – Wolfe's algorithm and Beale's algorithm. [25]

**References :**


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|---|---|---|
| G.Hadley | : | Non-linear and Dynamic Programming. |
| K.G.Murthy | : | Linear and Combinatorial Programming. |

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|---|---|---|
| P.Whittle | : | Optimization under Constraints. - Theory and Applications of Non-linear Programming. |
| S.S.Vajda | : | Probabilistic Programming. |
| N.S.Kambo | : | Mathematical Programming Techniques. |
| S.S.Rao | : | Optimization - Theory and Applications. |
| K.V.Mittal | : | Optimization Methods. |

**Module 4: Econometrics & Financial Statistics**

**Objective & Outcome**: This course provides an introduction to some standard econometric methods and their applications; for example, simultaneous equations, panel data, introductory nonparametric and Bayesian econometrics, demand and production function analysis etc. The course emphasizes intuitive and conceptual understanding as well as hands on econometric analysis using modern computer software (like R) on data sets from economics and business. Students learn how to conduct empirical studies, as well as how to analyze and interpret results from other empirical works. Course on Statistics in Finance is a contemporary course in financial statistics. This course covers standard topics like option pricing, portfolio management and value-at-risk. After completion of this advanced course students may opt for research in econometrics and finance. Apart from that finance is one of the important areas where job opportunities are growing day by day

**Section I: Advanced Econometric Methods**

Single-equation linear model – some variations. Nonparametric methods in econometrics.

Simultaneous Equations – identification & estimation.
Analysis of Panel Data. Bayesian Econometrics.
Demand Analysis. Production Function Analysis. Analysis of some special econometric models. [25]

**References :**

| | | |
|---|---|---|
| J.Johnston | : | Econometric Methods |
| G.G.Judge, et.al. | : | The Theory and Practice of Econometrics |
| W.Greene | : | Econometric Analysis |
| A.Zellner | : | An Introduction to Bayesian Inference in Econometrics |
| E.Malinvaud | : | Statistical Methods in Econometrics |
| H.Wold & L.Jureen | : | Demand Analysis – a study in econometrics |
| P.Sankhayan | : | An Intro.to the Economics of Agricultural Production |
| M.Nerlove | : | Estimation & Identification of Cobb-Douglas Models |
| A.Pagan & A.Ullah | : | Non-parametric Econometrics |

**Section II: Statistics in Finance**

The value of time, Bond Pricing with a flat term structure, The term structure of interest rates and an object lesson,The Mean Variance Frontier, The global minimum variance portfolio, Efficient portfolio, The zero beta portfolio,Allowing for a riskless asset, Efficient sets with risk free assets, Pricing of futures contract, Binomial option pricing, Multiperiod binomial pricing, Basic Option Pricing, the Black Scholes formula, Extending the Black Scholes formula, Dividends. Risk-free and risky assets. Contracts and options. Continuously compounded interest, present valuation, risk, risk-neutral valuation.

Arbitrage: examples, contracts and options under no-arbitrage assumptions.

Option Pricing: Cox-Ross-Rubinstein Binomial and Black-Scholes models. Elementary portfolio management, Value-at-risk. [25]

**References :**


S. M. Ross : Introduction to Mathematical Finance: Options and Other Topics.

N. H. Bingham & R. Kiesel : Risk-Neutral Val. : Pricing & Hedging of Financial Derivatives.

V. S. Bawa, S. J. Brown, R. W. Klein: Estimation Risk and Optimal Portfolio Choice.