UNIVERSITY OF KERALA

Outcome Based Scheme & Syllabus for M.Sc. Statistics

2021 Admission onwards

Outcome Based Syllabus for M.Sc. (Statistics) Semester Pattern in

Affiliated Colleges

2021 Admission onwards

Course Structure and Marks distribution

Semester No.	Course Code	Course Title	Hours/ Semester (Theory +Practical)	Instructional Hours per week		Duration of ESE (In hours)	Total Marks		
				Theory	Practical		CA	ESE	Total
1	ST 511	Analytical Tools for Statistics - I	90	5	-	3	20	60	80
	ST 512	Analytical Tools for Statistics - II	90	5	-	3	20	60	80
	ST 513	Probability Theory - I	90	5	-	3	20	60	80
	ST 514	Sampling Techniques	90	5	-	3	20	60	80
	ST 515	Introduction to R and Python	54 + 36	3	2	3	20	60	80
2	ST 521	Probability Theory - II	90	5	-	3	20	60	80
	ST 522	Distribution Theory	90	5	-	3	20	60	80
	ST 523	Applied Statistics & Numerical Methods	90	5	-	3	20	60	80
	ST 524	Statistical Quality Control &Reliability Modelling	90	5	-	3	20	60	80
	ST 525	Practical 1 Using R	90	-	5	3	20	60	80
3	ST 531	Theory of Estimation	90	5	-	3	20	60	80
	ST 532	Testing of Hypotheses	90	5	-	3	20	60	80
3	ST 533	Multivariate Analysis	90	5	-	3	20	60	80
	ST 534	Operations Research	90	5	-	3	20	60	80
	ST 535	Elective I	90	5	-	3	20	60	80

4	ST 541	Design and Analysis of Experiments	90	5	-	3	20	60	80
	ST 542	Stochastic Processes	90	5	-	3	20	60	80
	ST 543	Regression Methods	90	5	-	3	20	60	80
	ST 544	Elective II	90	5	-	3	20	60	80
	ST 545	Practical 2 Using R	90	-	5	3	20	60	80
	ST 546	Project/ Dissertation/ Internship							100*
	ST 547	Comprehensive Viva							100**
Grand Total									**1800**

Abbreviations used: ESE- End Semester Exam, CA- Continuous Assessment.

*80 marks for Project/ Dissertation/ Internship and 20 marks for viva voce examination based on it

** General viva voce based on all the courses.

Elective Papers

III Semester- Elective –I ST(235)

1. Machine Learning
2. Order Statistics
3. Biostatistics

IV Semester- Elective –I I ST(235)

1. Time Series and Forecasting
2. Bayesian Inference
3. Actuarial Statistics

During Semester 3, Elective I has to be chosen from among the three papers given and during semester IV, Elective II has to be chosen from among the three papers

Lab Requirements

For the courses ST 515 and ST 545, computers capable of installing and running R Packages and Python, along with stable internet connection should be necessary ..

Pattern of Question Papers for the End Semester Examination

Theory Papers:

For each paper the duration of the examination is 3 hours and maximum mark is 60. The question paper will have 3 parts: Part A, Part B and Part C. Part A will consist of 8 short answer questions (two questions from each of the 4 modules), each carrying 3 marks and a candidate has to answer any 4 of them. Part B will consist of 6 questions (3 questions each from module I and module II), each carrying 8 marks and the candidate has to answer 3 questions from this part. Part C will consist of 6 questions (3 questions each module III and module IV) each carrying 8 marks and the candidate has to answer 3 questions from this part.

Practical Papers:

The practical paper will be conducted using R programme. For each practical paper, a record of work done by the student should be prepared and submitted for internal evaluation. The components of CA mark for the practical paper are Attendance (4 marks), Record book (8 marks) and class test (8 marks). The Board of examiners will prepare the question paper for the practical examination (ESE) specified in the syllabus of Practical. An external examiner along with an internal examiner, appointed by the University will conduct the practical examination and its evaluation. For each practical paper, the duration of the examination is 3 hours and the maximum mark is 60.

For Practical 1, three data sets should be given for Data Analysis which cover the topics in ST 525. Each question should contain a minimum of three objectives and any two data sets should be analyzed.

For Practical 2, three data sets should be given for Data Analysis which cover the topics in ST 545. Each question should contain a minimum of three objectives and any two data sets should be analyzed.

Project/Dissertation/Internship:

A Project/Dissertation/Internship work has to be done and a report to be submitted at the end of the fourth semester. The project/dissertation/Internship report of 30 to 40 pages should consist of literature review, methodology, data analysis and summary.

SEMESTER: 1
COURSE CODE: ST 511
COURSE TITLE: ANALYTICAL TOOLS FOR STATISTICS – I

Course outcomes

On completion of the course, the students should be able to:

CO1. Describe classes of open and closed sets of R.

CO2. Describe the concept of compactness

CO3. Describe Metric space - Metric in R^n.

CO4. Use the concept of Cauchy sequence, completeness, compactness and connectedness to solve the problems

CO5. Explain the concept of Riemann- integral and describe the properties of Riemann- integral.

CO6. Apply integral calculus in problem solving

CO7. Compute Partial derivatives of functions of several variables

CO8. Compute maxima, minima of functions

CO9. Compute conditional maxima and conditional minima

CO10. Visualize complex numbers as points of R^2

CO11. Understand the significance of differentiability and analyticity of complex functions leading to the Cauchy–Riemann equations.

CO12. Evaluation of contour integrals using Cauchy's theorem and Cauchy integral formula

CO13. Learn Taylor and Laurent series expansions of analytic functions, classify the nature of singularity, poles and residues

CO14. Apply Cauchy Residue theorem in evaluating integrals

Sl. No:	**Outcomes** On completion of each module, students should be able to:	**Taxonomy Level**
MODULE: I	MO1. Describe classes of open and closed set MO2. Apply the concept of compactness MO3. Describe Metric space - Metric in R^n. MO4. Use the concept of Cauchy sequence, completeness, compactness and connectedness to solve the problems	Understand Understand Understand Apply
MODULE II.	MO1. Explain the concept of Riemann- integral MO2. Solve integration problems MO3. Apply integral calculus in solving statistical problems M04: Compute Partial derivatives of functions of several Variables M05: Compute maxima, minima of functions M06: Compute conditional maxima and conditional minima MO7: Apply partial derivatives, maxima and minima in statistics	Understand Evaluate Apply Evaluate Evaluate Evaluate Apply
MODULE III	MO1.Understand the concept of Complex numbers MO2. Significance of differentiability and analyticity of complex functions MO3. Evaluate integrals using Cauchy's theorem MO4. Evaluate integrals using Cauchy integral formula MO5. Apply Liouville's theorem	Understand Understand Evaluate Evaluate Apply
MODULE IV	MO1. Learn Taylor and Laurent series expansions of analytic functions	Understand

	MO2. classify the nature of singularity, poles and residues	Evaluate
	MO3. Understand the basic concepts of contour integration	Understand
	MO4 Apply Cauchy Residue theorem in evaluating integrals	Apply

Course content

Module I

Euclidean space R^n, open balls, open sets, closed sets, adherent points. Bolzano – Weierstrass theorem, Cantor intersection theorem, compactness in R^n, Heine-Borel theorem, Metric space (definition and examples). Compact subsets of a metric space, convergent sequence, Cauchy sequence, complete metric space

Limit of real valued functions, continuous functions, continuity and inverse images of open and closed sets, Connected sets, uniform continuity and monotone functions (definition examples and applications only). Functions of bounded variation, properties, total variation and additive property, continuous functions of bounded variation.

Sequences of functions, uniform convergence, Cauchy's conditions.

Chapter 3 , Chapter 4[Sections 4.1 – 4.5, 4.8, 4.9, 4.12, 4.13, 4.16, 4.19, 4.20, 4.23] , Chapter 6 [Sections 6.1- 6.8] and chapter 9[Sections 9.1–9.5] of Apostol T. M

Module II

Definition and existence of Riemann integral, Riemann-Stieltjes integral, its reduction to Riemann integral, properties of Riemann-Stieltjes integrals (viz. linearity, product, quotient and modulus of integrals). Riemann's Condition, Fundamental theorem of integral calculus, mean value theorems,

Functions of several variables, partial derivatives, maximum and minimum of functions, conditional maxima and minima, Lagranges multiplier method.

Chapter 7 [Sections 7.1 – 7.5, 7.7, 7.11, 7.13, 7.14, 7.18, 7.19, 7.20] of Apostol T. M and Chapter 9 [Sections 1 – 4] of Malik, S.C., Arora, S

Chapter 15 [Section 11] and Chapter 16 [Section 3] of Malik, S.C., Arora, S

Module II

Complex numbers and complex plane, functions of complex variables, analytic functions, Cauchy-Riemann equations (concepts and examples only). Cauchy's integral theorem, Cauchy's integral formula, Liouville's theorem, maximum modulus principle.

Chapter 1, Chapter 2[Sections 1,2,3] and Chapter 3[Sections 1-7] of Levinson,N., Redheffer ,M,R

Module IV

The zeros of analytic function, singularities and their types, residues, poles, Cauchy's residue theorem (statement and application only), contour integration (basic theory) and evaluation of integrals of the form:

$$\int_0^{2\pi} f(\sin\theta, \cos\theta)d\theta, \ \int_{-\infty}^{\infty} f(x)e^{imx}dx, \ \int_{-\infty}^{\infty} f(x)dx.$$

Chapter 3 [Sections 8-10], Chapter 4 [Sections 1-3] of Levinson,N., Redheffer ,M,R , and Chapter 5 [Section 3] of Ahlfors, L.V.

Texts:

1. Apostol T. M. (1974): *Mathematical Analysis*, Narosa Publishing House, New Delhi.
2. Malik, S.C., Arora, S. (2012): *Mathematical Analysis,* New Age International, New Delhi.
3. Levinson,N.,Redheffer ,M,R.(2015).*Complex Vaiables*.McGraw Hill Education(India) Limited.
4. Ahlfors, L.V.(2016). *Complex Analysis* .McGraw Hill Education(India) Limited.3rd Edition.

References:

1. Goldberg, R.R. (1970): *Methods of Real Analysis*, Oxford and IBH Publishing Company (P) Ltd, New Delhi.
2. Somasundaram, D, Chaudhary, B . (1999): First *Course in Mathematical Analysis*, Narosa Publishing House, New Delhi.
3. Lang, S.(1998). *Complex Analysis*. Springer , New York.

4. Ponnusamy ,S(2015). *Foundations of Complex Analysis* . Narosa Publishing House, New Delhi

COURSE CODE: ST 512
COURSE TITLE: ANALYTICAL TOOLS FOR STATISTICS – II

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1. Have a clear understanding of vector space, subspaces, independence of vectors, basis, dimension and Gram Schmidt orthogonalization

CO2. Understand different types of matrices, concept of determinants, rank of a matrix, nullity and partitioned matrices with the help of examples.

CO3. Define Characteristic roots and vectors and their properties, determination of characteristic roots- power method and Jacobi method, spectral decomposition of matrices, Cayley-Hamilton theorem, algebraic and geometric multiplicity

CO 4. Achieve ideas on quadratic forms and reduction of quadratic forms and gets ability for solving problems in these areas.

CO5. Understand the concept of generalized inverse, Moore-Penrose g-inverse and derives its properties.

CO6. Understand different methods of solving a system of linear equations

MODULE OUTCOME

SL. NO	**Outcomes** On completion of each module, students should be able to:	**Taxonomy Level**
Module I	M01. Articulate and exemplify the concepts of vector space, subspace, independence of vectors, basis and dimension, inner product, norm M02. Explain the concept of inner product, norm M03. Describe Gram Schmidt orthogonalization, orthogonal transformation.	Understand Understand Understand

Module II	M01. Describe different types of matrices- Triangular, Idempotent, nilpotent, nonnegative, Unitary, Hermitian and skew Hermitian matrices M02. Concept of determinants and its properties M03. Explain the rank and nullity of a matrix, rank nullity theorem.	Understand Apply understand
Module III	M01. Determine the Eigen values and Eigen vectors of the given matrix M02. Application of Cayley Hamilton theorem M03. Obtain the diagonal form and triangular form of a given matrix. M04. Write down the spectral decomposition M05. Understanding Algebraic and geometric multiplicity of characteristic roots	Understand Apply Understand Understand Understand
Module IV	M01. Find the nature of the quadratic form. M02. Articulate the concept of generalized inverse. M03. Obtain the g-inverse and Moore- Penrose g-inverse of the given matrix. M04. Solving a system of linear equations - inversion, elimination, iterative	Analyze Understand Apply Apply

Course content

Module I

Linear vector space, subspace, independence of vectors, basis and dimension, inner product, norm, orthonormal basis, orthogonal subspaces, Gram Schmidt orthogonalization, orthogonal transformation.

Module II

Matrices, Different types of matrices- Triangular, Idempotent, nilpotent, nonnegative, Unitary, Hermitian and skew Hermitian matrices. Determinants and their properties. Rank of a matrix, null space, nullity, partitioned matrices, Kronecker product, linear transformations, matrix representation of linear transformations, similarity of transformation.

Module III

Characteristic roots and vectors of matrices and their properties, determination of characteristic roots- power method and Jacobi method, spectral decomposition of matrices, Cayley- Hamilton theorem, algebraic and geometric multiplicity of characteristic roots.

Module IV

Quadratic forms- definition, classification and reduction of quadratic forms, real, symmetric and orthogonal reduction, simultaneous reduction, scalar valued functions of vectors and their derivatives with respect to a vector/matrix, Jacobian transformation.

Methods of computation of inverse of a non singular matrix, generalized inverse, reflexive inverse, solutions of matrix equations, determination of Moore- Penrose g-inverse, solution of a system of linear equations-methods of solution (inversion, elimination, iterative).

Text Books:

1. Biswas, S. (2012). Textbook of Matrix Algebra, Third edition, PHI Learning Pvt Ltd, New Delhi.
2. Sundarapandian, V. (2008). Numerical Linear Algebra, PHI Learning Pvt. Ltd,New Delhi.

Reference Texts:

1. Banerjee, S and Roy, A (2014). Linear Algebra and Matrix Analysis for Statistics, CRC Press, New York
2. Healy, M. J. R. (1986). Matrices for Statistics, Oxford Science Publications.
3. Lay, D. C. (2006). Linear Algebra and its Applications, Pearson Education.
4. Lipschutz, S. and Lipson, M. (2005). Linear Algebra. Tata McGraw- Hill Publishing Co. Ltd. New Delhi.
5. Monahan J.F. (2001). Numerical Methods of Statistics, Cambridge University Press.
6. Rao, C.R. (1973). Linear Statistical Inference and its Applications, Wiley Eastern

COURSE CODE: ST 513

COURSE TITLE: PROBABILITY THEORY I

Course Outcomes

On completion of the course, students should be able to:

CO1. Explain Sequence of sets and its convergence.

CO2. Describe various types of measures and explain its properties.

CO3. Explain Lebesgue and Lebesgue-Stieljes measures and its properties.

CO4. Explain measurable functions and its convergence

CO5: Explain probability measure and probability space.

CO6: Explain conditional probability and Baye's theorem.

CO7. Identify various types of random variables and explain its properties

CO8. Decompose distribution function.

Module Outcomes

Sl.No	**Outcomes** On completion of each module, students should be able to:	**Taxonomy Level**
Module I	M01. Explain and exemplify the concepts of sequence of events M02. Construction of the various types of fields. M03. State and explain various measures associated with a set function. M04. Explain the concepts of measurable functions. M05. Explain sequence of measurable functions and its convergence.	Understand Understand Remember Remember Create
Module II	M01. Integral of simple functions and measurable functions' M02. Evaluation of Lebesgue integral and Lebesgue- Stieltjes integral. M03.Describe Lebesgue decomposition theorem and Radon- Nykodym theorem	Apply Apply Understand
Module III	M01. Construct counter examples for proving/illustrating certain results associated with probability measure M02. Evaluate the conditional probability and verify its properties	Evaluate Apply Evaluate

	M03. Articulate the Bayes theorem and apply it to calculate priori probabilities	
Module IV	M01. Describe random variables and find the functions for various random variables M02.Explain distribution function and its properties. M03. Describe the decomposition of distribution function	Apply Understand Evaluate

Course Content

Module I

Sequence of sets, limit supremum, limit infimum and limit of sequence of sets, Monotone sequence of sets. Class of sets- Semi ring, ring, sigma ring (definition and examples only), field and sigma field. Borel sigma field and monotone class. Definition of minimal sigma field, generated sigma field and induced sigma field. Set functions, additive set functions and sigma additive set functions. Measure and its properties. Measure space, finite measure, sigma finite measure, complete measure, counting measure and signed measure (definition and examples only) Outer measure, Lebesgue measure, Lebesgue –Stieltjes measure, Caratheodory extension theorem (statement only). Measurable functions and properties (viz. linearity, product, maxima, minima, limit sup, limit inf,and modulus of measurable functions). Simple functions. Sequence of measurable functions. Point-wise convergence, almost everywhere convergence, uniform convergence, convergence in measure, convergence in p^{th} mean (concept only).

Module II

Integral of non- negative simple function, integral of non-negative measurable functions and integral of measurable functions. Lebesgue integral and its properties. Monotone convergence theorem, Fatou's theorem, Lebesgue dominated convergence theorem. Lebesgue –Stieltjes integral and its reduction to Riemann-Stieltjes integral and Riemann integral. Absolute continuity and singularity of measures (definition only). Statement and applications of Lebesgue decomposition theorem and Radon-Nykodym theorem

Module III

Sample space and events, probability measure, probability space. Limit of sequence of events, monotone and continuity properties of probability measure. Independence of sequence of events, conditional probability and Bayes theorem. Borel- Cantelli lemma, Borel zero-one law and Kolmogorov 0-1 law.

Module IV

Random Variables, discrete and continuous-type random variables, induced probability measure and induced probability space, probability distribution and distribution function, properties of distribution function., mixture of distribution functions (concept only). Decomposition of distribution function-Jordan decomposition theorem. Functions of a random variable, random vectors, distribution function of random vector (concept only). Independence of sequence of random variables.

Text books:

1. Jain, ,P.K. and Gupta, V.P.(2000). Lebesgue Measure and Integration, New Age International (P) Ltd., NewDelhi(For Unit 2).
2. Kingman, J.F.C. and Taylor, S.J. (1977). A text book of Introduction to Measure Theory and Probability, 3rdEdn., Cambridge University Press, London (For Unit 1, Unit 2 and Unit 3).
3. Laha, R.G. and Rohatgi, V.K. (1979).Probability Theory, John Wiley, New York(For Unit 4 and Unit 5).
4. Rohatgi, V.K. and Saleh, Ehsanes (2014). An Introduction to Probability Theory and Mathematical Statistics, Wiley Eastern Ltd.(For Unit 4 and Unit 5)
5. Roussas, G.G.(2014). An Introduction to Measure-Theoretic Probability, Academic Press, USA.

References:

1. Malik, S.C. and Arora, S.(2011) Mathematical Analysis, 4th Edn New Age international (P) Ltd, New Delhi.
2. Bhat, B.R.(1991). Modern Probability Theory, 2ndEdn., Wiley Eastern Ltd., New Delhi.
3. De Barra, G. (2000). Measure Theory and Integration, New Age International (P) Ltd.,
   NewDelhi.
4. Feller W. (1968) Introduction to Probability Theory and Its Applications Vol. 1 and 2, John Wiley, New York.
5. Loeve, M (1968) Probability Theory Allied East-West Press.
6. Mukhopadhyay, P. (2011). An Introduction to the Theory of Probability, World Scientific Publishing Company.

COURSE CODE: ST 514
COURSE TITLE: SAMPLING TECHNIQUES

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1. Understand the principles underlying sampling as a means of making inferences about a population.

CO2. Collect data from a smaller part of a large group so that the students can able to learn something about the larger group.

CO3. Understand the difference between randomization theory and model based analysis.

CO4. understand the concepts of bias and sampling variability and strategies for reducing these.

CO5. Understand the sampling schemes like SRS, Stratified sampling, Systematic sampling, Cluster sampling, Multi stage sampling, sampling with varying probabilities of selection etc.

CO6. Have an appreciation of the practical issues arising in sampling studies.

MODULE OUTCOMES

Sl. No:	**Outcomes** On completion of each module, students should be able to:	**Taxonomy level**
Module I	M 01.Explain population, sample, sampling and non-sampling errors, sampling frame, probability and non-probability sampling, sampling design, sampling strategy.	Understand
	M02.Discuss simple random sampling with and without replacement.	Analysis
	M03. Articulate the estimation of population mean, total and proportion and hence the estimation of the standard error.	Evaluate
	M04. Explain determination of sample size and confidence interval	Apply

	M01. Explain PPS sampling and articulate to selection procedures using PPS with and without replacement M02. Find methods to estimate population mean, total and variance with respect to PPS sampling M03. Apply various selection procedures for selecting samples using PPS	Evaluate Analysis Remember
Module II	M01. Explain the purpose of stratification M02. Explain stratified random sampling M03. Discuss various allocation procedures M04. Explain systematic sampling M05.estimation of the population mean and variance of the estimator under systematic sampling M06. Describe the comparison of simple random sample, systematic sample and stratified sample for a population with linear trend.	Apply Understand Analysis Understand Analysis Evaluate
Module III	M01. Explain PPS sampling and articulate to selection procedures using PPS with and without replacement M02. Find methods to estimate population mean, total and variance with respect to PPS sampling M03. Distinguish between ordered and unordered sampling method M04. Des Raj's ordered estimator, Murthy's unordered estimator, Horvitz-Thompson estimator, Yates- Grundy form of estimated variance, Zen-Midzuno scheme of sampling , πps sampling	Understand Evaluate Understand Evaluate

Module IV	M01. Distinguish between ratio and regression estimators M02. Explain various properties of ratio and regression estimators M03. Explain cluster sampling. M04. Estimation of population mean and variance of the estimator and efficiency of cluster sampling. M05. Explain Two stage sampling M06. Estimation of population mean and variance M07. Comparison of two-stage with one stage	Understand Evaluate Understand Apply Understand Evaluate Evaluate

COURSE CONTENT

Module I

Concept of population and sample, sampling and non-sampling errors, sampling frame, probability and non-probability sampling, concept of sampling design, sampling strategy, simple random sampling with and without replacement, procedures for selection of simple random sample, Estimation of population mean, population total, population proportion, and the variance of these estimators. Estimation of their standard errors. Confidence limits for population mean and for proportion. Estimation of sample size.

Module II

Stratified sampling, procedure of sample selection, estimation of population mean and variance of the estimator, choice of the sample size in different strata (optimum allocation, Neyman allocation and proportional allocation), variance of the estimator of population mean under these allocations, comparison of these variances, comparison of stratified sampling with SRS.

Systematic sampling- sample selection procedure, estimation of the population mean and variance of the estimator, comparison of systematic sampling with SRSWOR, comparison of systematic sampling with stratified sampling, comparison of systematic sampling with SRSWOR and stratified random sampling for population with linear trend, circular systematic sampling- sample selection procedure.

Module III

Sampling with varying probabilities: PPS sampling with replacement, method to select PPSWR sample, estimation of population mean and variance of the estimator, PPS sampling without replacement, Des Raj's ordered estimator, mean of the estimator for the case of two draws and general case, Murthy's unordered estimator(Definition only), Horvitz-Thompson estimator of population mean and variance of the estimator, Yates-Grundy form of estimated variance, Zen-Midzuno scheme of sampling (concept only), πps sampling (definition only)

Module IV

Ratio method of estimation - Ratio estimator, bias and MSE of the ratio estimator, first order approximation to the bias of ratio estimator, approximate variance of ratio estimator.

Regression method of estimation – Difference estimator, the regression estimator, bias and MSE of the regression estimator, comparison of regression estimator with ratio estimator, approximate variance of the regression estimator

Cluster sampling- cluster sampling with clusters are of equal size, estimation of population mean and variance of the estimator, efficiency of cluster sampling. Two stage sampling-Two stage sampling with equal first stage units, estimation of the population mean and the variance of the estimator. Comparison of two-stage with one stage sampling. Multistage sampling (concept only).

Text Books

1. Bensal A (2017). Survey Sampling, Narosa Publishing House Pvt. Ltd.
2. Cochran, W. G. (1977). Sampling Techniques, Third edition, Wiley Eastern Ltd.
3. Mukhopadhyay, M. (2009). Theory and Methods of Survey Sampling, Second Edition, PHI Learning Pvt. Ltd.

References

1. Gupta A K and Kabe D G (2011), Theory of Sample Surveys, World Scientific.
2. Murthy, M. N. (1967). Sampling Theory and Methods, Statistical Publishing Society, Calcutta.
3. Sampath, S. (2001). Sampling Theory and Methods, Second edition, Narosa Publishing Company, New Delhi.
4. Singh, D. and Chaudhary, F.S. (1986). Theory and Analysis of Sample Survey Designs, Wiley Eastern Ltd.
5. Sukhatme, P.V. and Sukhatme, B.V. (1970). Sampling Theory of Surveys with Applications, second edn, Asia Publishing House, Bombay.

COURSE CODE: ST 515

COURSE TITLE: INTRODUCTION TO R AND PYTHON

Course Outcomes

After completion of this course the students will be able to:

C01. Write programs for statistical applications using R and Python.

C02. Use R and Python graphical functions/packages to create plots.

C03. Learn basic data handling methods using R and Python.

CO4. Crete user defined functions in R and Python.

Module Outcomes

Sl.No.	Outcomes On Completion of each module, Students should be able to:	Taxonomy level
MODULE I.	MO1.Download and install R and R packages MO2. Apply R syntax and R objects MO3.Apply built in functions in R MO4.Reshape and manipulate Data MO5. Write own functions in R	Remember and Apply Understand and Apply Understand and Apply Understand and Apply Understand and create
MODULE II	MO1.Apply Graphical functions in R MO2.Write programs to create graphs/plots	Understand and Apply Apply and Create

MODULE III	MO1. Installing and running python MO2. Basic python commands and operations MO3. Learn control structures, iteration and data types	Remember and Apply Understand and apply Learn and apply
MODULE IV	MO1. Creating functions in Python MO2. Learning Data Visualization in Python MO3. Creation of diagrams and graphs	Learn Learn and apply Understand and Apply

Course Content

MODULE I

Installing R, R user interface, Expressions, objects, symbols, functions, special values (NA, Inf and –Inf, NaN, NULL), Constants, Numeric vectors, Character vectors, Symbols, Order of operations, Assignments, Conditional statements, Loops, indexing by Integer vector, indexing by Logical vector, indexing by Name. **R Objects**:- Object types, vectors, lists, matrices, arrays, missing values, factors, data frames.

Functions - The function keyword, Arguments, Return values, Functions as arguments, Anonymous functions, properties of functions, calling basic functions, math functions, vector and matrix operations, statistical functions, Reading Data into R- Reading CSVs, Excel Data, Manipulating Data- Apply family of functions Data Reshaping- cbind, rbind, joins, basic string operations.

MODULE II

R-Graphics: - An overview of R graphics, Scatterplots, Bar charts, Histogram, Pie charts, Plotting time series, Box plots, Lattice Graphics, Stem and leaf plots, Q-Q plots, Graphical parameters, Basic graphic functions, Drawing- mathematical functions, Logarithmic functions, Trigonometric functions, polynomial functions, dot chart and violin plot examples,.

MODULE III

Installing Python, Basics of Python Programming, Running Python Scripts, Using the Terminal Command Prompt, IDEs for python, Variables, Assignment, Keywords, Input-Output, Indentation. Types, Operators and Expressions: Types - Integers, Strings, Booleans; Operators- Arithmetic Operators, Comparison (Relational) Operators, Assignment Operators, Logical Operators, Bitwise Operators, Membership Operators, Identity Operators, Expressions and order of evaluations Control Flow- if, if-elif-else, for, while, break, continue, pass, Exception handling. Data Structures: Lists - Operations, Slicing, Methods; Tuples, Sets, Dictionaries, Built-in methods of lists, sets and dictionaries, Mutable and Immutable Objects.

MODULE IV

Functions: Defining Functions, Calling Functions, Passing Arguments, Recursion, Keyword Arguments, Default Arguments, Variable-length arguments, Anonymous Functions, Fruitful Functions (Function Returning Values), Scope of the Variables in a Function - Global and Local Variables. Basic plot functions in Matplotlib library: Line Plot, Bar Plot, Pie Chart, Box Plot, Histogram Plot, Scatter Plot.

TEXTBOOKS

1. Adler, J. (2010). *R in a nutshell: A desktop quick reference*. " O'Reilly Media, Inc.".
2. Chun, W. (2006) Core python programming. Prentice Hall Professional.
3. Embarak, O. (2018). Data Analysis and Visualization Using Python: Analyze Data to Create Visualizations for BI Systems. Apress.
4. Lambert, K. A. (2011). Fundamentals of Python: First Programs. Cengage Learning.
5. Wickham, H. & Grolemund, G. (2018). R for Data Science. O'Reilly: New York. Available for free at http://r4ds.had.co.nz

REFERENCES

1. Braun, W. J., & Murdoch, D. J. (2016). *A first course in statistical programming with R*. Cambridge University Press.
2. Everitt, B.S. and Hothorn T. (2010) A Handbook of Statistical Analysis Using R, Second Edition, CRC Press.

3. Michael J. Crawley (2013) The R book, Second Edition, John Wiley & Sons Ltd.
4. Rubinstein, R.Y. (1981) Simulation and Monte Carlo Methods, Wiley.
5. Thereja, R. (2019). Python Programming Using Problem Solving Approach. Oxford University Press
6. Jackson, C. (2018). Learn Programming in Python with Cody Jackson, Packt Publishing
7. Balagurusamy, E. (2017). Introduction to Computing & Problem Solving using Python, McGraw Hill Education (India) Private Limited

SEMESTER : 2

COURSE CODE : ST 521

COURSE TITLE : PROBABILITY THEORY II

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1 : Calculate the expectation and moments of random variables.

CO2 : Identify the applications of various moment inequalities.

CO3 : Explain the concept of convergence and check for the of convergence of a given sequences of random variables.

CO4 : Find the expressions for the characteristic function of a random variable and verify its properties.

CO5 : Apply the various laws of large numbers to sequences of random variables.

MODULE OUTCOMES

Sl. No:	**Outcomes** On completion of each module, students should be able to:	**Taxonomy Level**
Module I	MO1 : Calculate the mathematical expectation, moments and generating functions of random variables. MO2 : Articulate the various moment inequalities MO3 : Apply the various moment inequalities to various distributions.	Evaluate Understand Apply
Module II	MO1 : Articulate and appraise stochastic convergence of sequence of random variables. MO2 : Apply the concepts of convergence to sequences of random variables. MO3 : Construct counter examples for not satisfying certain convergence implications.	Understand Apply Create
		Evaluate

Module III	MO1 : Derive expressions for the characteristic function for various distributions. MO2 : Find moments using characteristic function. MO3 : Derive expressions for the probability density function corresponding to a given characteristic function' MO4 : Articulate the various theorems associated with the characteristic function and identify their applications.	Evaluate Evaluate Apply
Module IV	MO1 : State and prove the various laws of large numbers. MO2 : Apply the laws to sequences of random variables. MO3 : State and prove various central limit theorems. MO4 : Applications of various central limit theorem.	Understand Apply Understand Apply

Module 1

Expectation of random variables and its properties, moments and factorial moments, probability generating function, moment generating function and cumulant generating function. Inequalities- Markov, Chebychev's, Lyapunov (for moments), Jensen, Holder's, C_r– inequality, Minkowski and basic inequality.

Module II

Stochastic convergence of sequence of random variables: - convergence in probability, almost sure convergence, convergence in p^{th} mean, weak and complete convergence of distribution functions and their interrelations. Slutsky's theorem and its applications. Helly-Bray lemma (statement only) and Helly-Bray theorem (statement only).

Module III

Characteristic function (c.f.) and their elementary properties, uniform continuity and non-negative definiteness of characteristic function. Uniqueness theorem, Inversion theorem (without proof), Fourier inversion theorem, Convolution theorem, Levy's continuity theorem (without proof) and Bochners theorem (without proof).

Module IV

Stochastic series of sequence of random variables: - Law of large numbers, weak law of large numbers due to Bernoulli, Tchebyhev and Khintchine. Kolmogorov inequality (statement only), Kolmogorov three-series theorem(statement only). Strong law of large numbers- Kolmogorov's strong law of large numbers for independent random variables (statement and applications only). Kolmogorov's strong law of large numbers for independent and identically distributed random variables (statement and applications only). Central limit theorem: Classical Central limit theorem, De Moivre-Laplace Central limit theorem, Statement of Lyapunov Central limit theorem and Lindberg-Feller Central limit theorem. Applications of various central limit theorems.

Text books

1. Bhat, B.R. (1991).Modern Probability Theory, 2ndEdn., Wiley Eastern Ltd., New Delhi.
2. Laha, R.G and Rohatgi, V.K. (1979). Probability Theory, John Wiley, New York.
3. Rohatgi, V.K. and Saleh, Ehsanes (2014). An Introduction to Probability Theory and Mathematical Statistics, Wiley Eastern Ltd.

References

1. Cacoullos, T. (1989). Exercise in Probability, Springer-Verlag, New-York.
2. Feller W. (1968). Introduction to Probability Theory and Its Applications Vol. 1 and 2, John Wiley, New York.
3. Gnedenko, B.V. (1969). The Theory of Probability, Mir Publishers, Mosko.
4. Loeve, M. (1968). Probability Theory Allied East-West Press.
5. Mukhopadhyay, P. (2011). An Introduction to the Theory of Probability, World Scientific Publishing Company.
6. Roussas, G.G.(2014). An Introduction to Measure- Theoretic Probability, Academic Press, USA.

COURSE CODE : ST 522

COURSE TITLE : DISTRIBUTION THEORY

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1.Understand various specifications such as probability density functions and cumulative distribution functions etc, of the probability distribution of a random variables.

CO2. Derive various generating functions of random variables such as probability generating function, moment generating functions, characteristic functions, etc.

CO3. Find out characteristics of random variables like moments from either probability density (mass) functions or the generating functions.

CO4. Understand the probability distribution of bivariate random variables and the terms marginal distributions, conditional distributions, marginal, joint and conditional moments.

C05. Apply transformation of variable technique for finding the distribution of functions of random variables and solve related problems

C06. Understand the properties and applications of some standard univariate and bivariate probability distributions for both discrete and continuous random variables.

CO7. Explain the concept of order statistics and solving problems related to it.

CO8. Explain different sampling distributions, and their properties and applications

MODULE OUTCOMES

Sl. No:	**Outcomes** On completion of each module, students should be able to:	**Taxonomy level**
Module I	M01. Explain the basic concepts of pgf, mgf and characteristic functions M02 Evaluate characteristics of random variables M03. Find out the joint, marginal , conditional distributions and characteristics of a bivariate distribution M04. Apply transformation of variable technique for finding the distribution of functions of random variables and solve related problems	Understand Apply Apply Analysis
Module II	M01. Understand the properties of standard univariate discrete distributions. M02 Articulate the connections between discrete distributions M03. Explain the how to apply the standard discrete distributions in various situations M04. Articulate multivariate discrete probability distributions such as multinomial and bivariate Poisson distribution	Understand Analysis Apply Analysis
Module III	M01. Understand the properties standard univariate continuous distributions. M02 Articulate the connections between continuous distributions M03. Explain the how to apply the standard continuous distributions in various situations M04. Understand the bivariate normal distributions and its applications	Understand Analysis Apply Understand
Module IV	M01. Explain the concept of order statistics M02. Find the joint distribution of two order statistics M03. Calculate Distribution of functions of two order statistics M04. Explain different sampling distributions M05. Find out expressions for probability density function of sampling distribution M06 Understand the applications of sampling distributions	Understand Apply Apply Understand Apply Apply

COURSE CONTENT

Module I

Generating functions (concepts and examples only) - probability generating function, moment generating function, cumulant generating function and characteristic function; bivariate distributions- joint, marginal and conditional distribution. Independence of random variables, bivariate mgf, pgf and moments, functions of random variables and their distributions, concepts of Compound, truncated and mixture distributions, definition and examples of Singular and Cantor distributions.

Module II

Discrete distributions- Degenerate, binomial, Poisson, negative binomial, geometric, uniform, hyper geometric distributions, Power series distributions- generalized power series and modified power series distribution, multinomial distribution.

Module III

Continuous distributions- uniform, normal, exponential, double exponential, beta, gamma, Cauchy, Weibull, Pareto, log-normal and logistic distributions. Pearson system of distributions, bivariate normal and Gumbel's bivariate exponential distribution.

Module IV

Order Statistics- definition and basic distribution theory of order statistics - joint, marginal and conditional distributions of order statistics of a random sample arising from continuous distributions, distribution of sample median and range.

Sampling distributions- distribution of the mean and variance of a random sample from normal population, Chi-square, t, and F distributions (both central and Non-central), their properties and applications.

Text books:

1. Rohatgi, V. K. and Saleh, (2003). An Introduction to Probability Theory and Mathematical Statistics, John Wiley and Sons.
2. Mukhopadhyay, P. (2006). Mathematical Statistics, Books and Allied (P) Ltd., Kolkatta.
3. Gumbel, E.J. (1960). Bivariate exponential distribution, JASA, Vol. 55,pp.698-707.

References:

1. Hogg, R.V. and Craig, A.T. (1995). Introduction to Mathematical Statistics, Fifth Edition, Prentice Hall N J
2. Johnson, N. L., Kotz, S. and Balakrishnan, N. (2004). Continuous Univariate Distributions, Vol I Second Edition, John Wiley and Sons (Asia), PVT Ltd, Singapore.
3. Johnson, N. L., Kotz, S. and Balakrishnan, N. (2004). Continuous Univariate Distributions, Vol II Second Edition, John Wiley and Sons (Asia), PVT Ltd, Singapore.

COURSE CODE : ST 523

COURSE TITLE : APPLIED STATISTICS AND NUMERICAL METHODS

COURSE OUTCOMES

On completion of the course, students should be able to:
CO1. Identify the various index numbers and compute them for data sets

CO2. Explain the concepts of base shifting, slicing and deflating of index numbers

CO3. Illustrate the applications of index numbers.

CO4. Understand the need, use, relevance and limitations of official statistics

CO5. Explain the roles and responsibilities of various organisations like NSSO, CSO etc.

CO6. Explain the methods of data collection and dissemination in population census

CO7. Identify the roles of various organisation s involved in the census procedure.

CO8. Explain the concepts of various measures of fertility and mortality.

CO9. Compute these fertility and mortality measures.

CO10. Distinguish between stationary and stable population.

CO11. Construct abridged life tables.

CO12. Understand the concepts of iteration and interpolation.

CO13. Apply various methods of interpolation to solve numerical problems.

CO14. Solve differential equations using Picard, Euler, Modified Euler and Runge-Kutta methods

MODULE OUTCOME

Sl. No:	**Outcomes** On completion of each module, students should be able to:	**Taxonomy Level**
Module I	M01. Explain the concept of index numbers and understand their applications M02. Explain and exemplify the various methods of constructing index numbers. M03. Distinguish between various index numbers and evaluate their values. M04. Explain the concepts of base shifting, splicing, and deflating. M01. Explain the need, uses, relevance and limitations of 'Official Statistics'. M02. Explain the roles and responsibilities of NSSO, CSO etc. M03. Articulate/exemplify various concepts associated with Population Census.	Understand Apply Evaluate Apply Understand Understand Apply
Module II	M01. Distinguish between the various measures of Fertility and Mortality and evaluate their values. M02. Explain concepts of stationary and stable population, central mortality, force of mortality. M03. Construct abridged life tables.	Evaluate Understand Create
Module III	M01. Articulate the various methods of iteration and interpolation. M02. Carry out various interpolation techniques to solve algebraic equations	Understand Apply
Module IV	M01. Solve differential equations using Picard, Euler, Modified Euler and Runge-Kutta methods.	Evaluate

Module I

Index numbers-definition and application of index numbers, price and quantity relatives, link and chain relatives. Computation of index numbers. Use of averages, simple aggregate, and weighted average methods, Laspeyre's, Paache's, Marshall-Edgeworth, Kelly's, Dorbish-Bowley and Fisher's index numbers. Criteria of a good index number. Consumer price index number. Base shifting, splicing and deflating index numbers.

Official Statistics: Indian statistical system - NSSO, CSO, RGI and their roles and responsibilities

Module II

Vital Statistics- Measurement of Fertility: Crude birth rate, General fertility rate, Age specific birth rate, Total fertility rate, Gross reproduction rate, Net reproduction rate. Measurement of Mortality: Crude death rate, Standardized death rates, Age-specific death rates, Infant Mortality rate, Death rate by cause. Mortality table, stationary and stable population, central mortality rate, force of mortality, construction of abridged life tables.

Module III

Numerical solutions of algebraic equations- method of iteration and Newton Raphson Method, Finite differences, Lagrange, Hermite and Spline interpolation,

Module IV

Numerical differentiation and integration, Numerical solutions of differential equations using Picard, Euler, Modified Euler and Runge-Kutta methods.

Text Books:

1. Mukhopadhyay, P. (1999), Applied Statistics, New Central Book Agency Pvt. Ltd, Calcutta.
2. Goon A.M., Gupta.M.K., and Dasgupta, B. (1986). Fundamentals of Statistics, Vol 2, World Press, Calcutta
3. Sastry, S. S. (2006). Introductory methods of Numerical Analysis (Fourth Edition), Printice Hall, New Delhi.
4. Barlow.R.E and Proschan, F (1985). Statistical theory of reliability and life testing, Holt, Rinehart and Winston.
5. Lawless J.F. (1982), Statistical Models and Methods of lifetime data, John Wiley & Sons, New York.
6. Montgomery, D.C. (2012). Introduction to Statistical Quality Control, 7th edn, John Wiley & Sons, New York.

References:

1. Anderson, T.W. (1971). Statistical Analysis of Time Series, John Wiley & Sons, New York.
2. Chatfield, C. (1980). The Analysis of Time Series-An introduction, 2nd edn, Chapman and Hall.
3. Medhi, J. (1992). Statistical Methods-An Introductory Text, New Age, Delhi.
4. Gupta, S.C. and Kapoor, V.K. (2007). Fundamentals of Applied Statistics, Sultan Chand & Sons
5. Grant. E. L. and Leavenworth, R.S. (1996). Statistical Quality Control, 7th edn, McGraw Hill Education (India) Private Limited, New Delhi.

COURSE CODE: ST 524

COURSE TITLE: STATISTICAL QUALITY CONTROL AND RELIABILITY MODELING

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1: Understand the concept of quality and statistical process control.

CO2: Evaluate the performance of a Statistical quality process control

CO3: Perceive the notion of statistical quality product control

CO4: Understand the basic reliability functions and their estimation and utilization to lifetime probability distributions useful in reliability analysis.

CO5: To know the notion of Ageing and interpret the reliability concepts in discrete set up

CO6: Understand the concept of reliability modeling.

MODULE OUTCOMES

Sl. No	Outcomes On completion of each module, students should be able to	Taxonomy Level
Module I	M01. Explain statistical process control M02. Describe various control charts	Understand Evaluate
Module II	M01. Describe Acceptance sampling inspection techniques M02. Explains Standardization and six-sigma concepts M03. Distinguish chain sampling and continuous sampling	Evaluate Understand Understand
Module III	M01. Explain basic concepts of reliability. M02. Describe reliability of a coherent system.	Understand Remember

	M03. Describe functions of reliability .	Remember
Module IV	MO1. Describe various censoring schemes M02. Describe estimation of parameters based on censored sampling MO3. Nonparametric evaluation of survival function	Understand Apply Evaluation

COURSE CONTENT

Module I

Meaning of quality and quality improvement. Basic SQC terminologies-Control limits, Specification limits and Natural tolerance limits. Statistical Process Control-chance and assignable causes of variation, Statistical basis of control charts, – Shewart control charts for variables- ,Mean, Range and S charts. Control charts for attributes - chart for fraction nonconforming- p-chart, np chart ,c and u charts – OC and ARL curve . CUSUM chart.

Module II

Acceptance sampling by attributes- Single sampling plan, Consumer's and Producer's risk, AQL and LTPD.Type A and Type B OC curves , Rectifying Inspection plan – AOQ , AOQL and ATI curves . Double, Multiple and Sequential sampling plans. Chain and Continuous sampling. Military Standard 105 E and six sigma concepts.

Module III

Basic Reliability concepts - system reliability, series and parallel systems, k out of n systems and its reliability, coherent systems, reliability of coherent systems, cuts and paths. Survival function, hazard function, mean residual life function, life time distributions- exponential, Weibull, gamma distributions-their survival and hazard functions.

Module IV

Observation schemes: censoring and trucation. Concept of left, right and interval censoring. Non-parametric estimation of survival function function: Kaplan-Meier estimator (definition and derivation only) .

Text Books:

1. Montgomery, D.C. (2012). Introduction to Statistical Quality Control, 7th edn, John Wiley & Sons, New York.
2. Grant. E. L. and Leavenworth, R.S. (1996). Statistical Quality Control, 7th edn, McGraw Hill Education (India) Private Limited, New Delhi
3. Lawless J.F. (1982), Statistical Models and Methods of lifetime data, John Wiley & Sons, New York
4. Barlow.R.E and Proschan, F (1985). Statistical theory of reliability and life testing, Holt, Rinehart and Winston

References:

5. Nelson, W. (1982): Applied life data analysis, Wiley.
6. Cox, D.R. and Oakes, D. (1984): Analysis of Survival Data, Chappman Hall .
7. Duncan A.J.(1959): Quality Control and Industrial Statistics, Irwin,Homewood I

8. Sinha, S. K. (1986) Reliability and Life Testing, Wiley.

COURSE CODE : ST 525
COURSE TITLE : PRACTICAL I USING R

MODULE I

DIAGRAMMATIC AND GRAPHICAL REPRESENTATION OF DATA: Graphics with R – standard plot functions and its arguments; Bar diagram, Sub-divided bar diagram, Multiple bar diagram, Pie chart, Line chart, Strip chart, Scatter plot, histogram, Ogives, line graphs, Box-and-Whiskers plot, Normality plots-P-P plots, QQ plots.

MODULE II

TABULAR REPRESENTATION OF DATA AND STATISTICAL MEASURES: Frequency tables, Contingency tables, Measures of Central Tendency, Measures of Dispersion, Skewness, Kurtosis, Correlation coefficient.

MODULE III

TESTS OF HYPOTHESES: Parametric tests: One sample and two samples tests for mean-Z-tests, t-tests; Tests of proportion,Tests of variances- Chi square and F –test; Analysis of variance- One-way and Two way; Non-parametric tests- Chi square tests for proportions, Chi square test for association, Run test, Kolmogorov- Smirnov test of normality, Mann-Whitney U test for equality of means or medians of two independent samples, Wilcoxon test for paired samples, Kruskal-Wallis H test for equality of means of independent samples, Friedman test for more than two dependent samples.

Examination: Three Data sets should be given for Data Analysis which cover the topics in three Modules(Should contain a minimum of three objectives) in the syllabus and two data sets should be answered.

SEMESTER: 3

COURSE CODE: ST 531
COURSE TITLE: THEORY OF ESTIMATION

Course Outcomes

On completion of this course, the students will be able to**:**

CO1: List the ideal properties of point estimators of an unknown parameter of a distribution and select the best estimators using different properties.

CO2: Derive the UMVUE of a parameter or function of a parameter.

CO3: Determine UMVUE using Rao Blackwell and Lehmann Scheffe Theorems

CO4: Determine estimators of unknown parameters using methods like MLE, Method of moments etc.

CO5: Realize the asymptotic properties of MLE

CO6: Understand Basics of Interval Estimation

C07: Differentiate between classical and Bayesian inference

C08: Outline Bayes estimation of parameters of standard distributions

CO9. Describe the role of the posterior distribution, the likelihood function and the posterior distribution in Bayesian inference about a parameter.

Sl.No.	Outcomes On Completion of each module, Students should be able to:	Taxonomy level
MODULE I	MO1 Know whether an estimator is unbiased MO2 Know whether an estimator is consistent MO3 Explain minimal sufficiency. MO4 Determine sufficient statistic by factorization theorem. MO5 Apply Basu's Theorem	Evaluate Evaluate Understand Create Apply

MODULE II	MO1 UMVUE and its propeties MO2 Apply Rao-Blackwell Lehmann-Scheffe theorems to find UMVUE. MO3 Understand Fisher Inormation measure MO4 Calculate Cramer-Rao inequality and Chapman -Robbin's bound.	Understand Apply Understand Evaluate Apply
MODULE III	MO1 Apply different methods of estimation- method of moments, MLE, Minimum & modified minimum chi-square MO2 Concepts of Interval Estimation MO3 Properties of MLE	Apply Understand Apply
MODULE IV	M01. Differentiate between classical and Bayesian Inference M02. Design basic elements of Bayesian Inference M03. Calculate Bayes estimators of parameters of standard distributions.	Understand Apply Apply

Module I

Point estimation: unbiasedness; Definition and examples of: mean square error, Bias of an estimator, asymptotically unbiased estimator. Consistency (strong, weak and squared error), Sufficient condition for weak consistency. Invariance property of consistent estimator, CAN estimator, BAN estimator. Sufficiency- Factorization criterion for sufficiency, Minimal Sufficient Statistic and its construction (concept and example). Completeness, complete sufficient statistics for exponential family of distributions, Ancillary statistic and Basu's theorem.

Module II

UMVU estimators and its properties, Rao-Blackwell theorem, Lehman-Scheffe theorem and its applications. Fisher's information measure, Cramer- Rao inequality and its generalizations through higher order derivatives, Bhattacharya bounds, Chapman-Robin's bound. Efficient estimators.

Module III

Methods of estimation- maximum likelihood, method of moments, method of minimum Chi-square, modified minimum Chi-square. Properties of MLE (such as function of sufficient statistic, invariance property, uniqueness). Theorems regarding consistent solution of likelihood equations (viz. uniqueness, asymptotically normal and efficient). Interval Estimation-(Basic concepts and definition only)

Module IV

Limitations of classical inference, decision rule, loss function. Bayes and minimax decision rules. Types of loss (squared and modulus). Prior distribution, Posterior distribution, Bayes solution (Theorem associated to quadratic loss and problems in case of binomial and Normal). Conjugate prior family. Jeffrey's Prior.

Text Books:

1. Rohatgi, V. K. and Saleh, A.K.M (2001). An Introduction to Probability and Statistics, 2nd edn, John Wiley and Sons.
2. Mukhopadhyay, P. (2006). Mathematical Statistics, Books and Allied (P) Ltd., Kolkatta.
3. Rajagopalan, M. and Dhanavanthan, P. (2012). Statistical Inference, PHI Learning Pvt Ltd, New Delhi.

References:

1. Casella, G. and Berger, R.L. (2002). Statistical Inference, 2nd edn. Cengage Learning, New Delhi
2. Lehmann, E.L. (1983). Theory of Point Estimation, Wiley, New York.
3. Rao, C.R. (1973). Linear Statistical Inference and Its Applications, 2/e, Wiley Eastern Ltd.
4. Wasan, M.T. (1970). Parametric Estimation, Mc-Graw Hill, New York.
5. Ferguson, T.S. (1967). Mathematical Statistics. Academic Press, New York.
6. Kale B.K. (1999). A First Course on Parametric Inference. Narosa Publishing House.
7. Mood, A.M, Graybill F.A. and Boes D.C. (2001). Introduction to the Theory of Statistics, 3rd edn., Mc- Graw Hill Inc, New York.
8. Srivastava, Khan and Srivastava (2014), Statistical Inference: Theory of Estimation, PHI, India

COURSE CODE: ST532

COURSE TITLE: TESTING OF HYPOTHESES

COURSE OUTCOMES

On completion of this course, the students will be able to**:**

C01: List out the fundamental concepts of testing of hypothesis.

C02: Formulate hypothesis for a given problem.

C03: Find most powerful test for testing simple hypothesis against simple alternatives.

CO 4: Find UMP test for testing composite hypothesis.

CO 5: Derive likelihood ratio test for testing the hypothesis for normal populations.

CO 6: Obtain sequential probability ratio test for testing the hypothesis.

CO7: Obtain OC function and ASN function for Binomial, Poisson and Normal distributions.

CO8: Perform a suitable non-parametric test for a given data.

MODULE OUTCOMES

Sl.No.	Outcomes On completion of each module, students should be able to:	Taxonomy level
Module I	MO1: Distinguish between randomized and non-randomized test. MO2: Apply Neyman-Pearson lemma to find most powerful test. MO3: Find UMP for simple hypothesis. MO4: Articulate monotone likelihood ratio property. MO5: Find UMP test for composite hypothesis	Identify Apply Apply Understand Apply
Module II	MO1: Find UMPU test. M02: Explain generalizations of Neyman-Pearson lemma. M03: Articulate α- similar test and LMP test. M04: Articulate the connection between test of hypothesis and confidence set.	Evaluate Understand Understand Evaluate

	MO5: Apply likelihood ratio test principle for testing the mean and variance for a normal population. MO6: Apply likelihood ratio test principle for testing the equality of means and variances for two normal population	Apply Apply
Module III	MO1: Articulate sequential probability ratio test. MO2: Derive SPRT for test the parameters of normal distribution, binomial and Poisson distributions. MO3: Identify Walds fundamental identity. MO4: Find OC function and Average Sample Number of a SPRT.	Understand Apply Understand Understand
Module IV	MO 1 : Perform chi square test of goodness of fit MO 2 : Perform one sample non-parametric test. MO 3 : Perform two sample non-parametric test. MO4 : Apply Spearman's rank correlation coefficient and Kendall's Tau for testing association.	Apply Apply Apply Apply

COURSE CONTENT

Module I

Fundamental concepts of hypothesis testing, test function, randomized and non-randomized tests, size and power function of a test, most powerful (MP) test and uniformly most powerful (UMP) test; Test of a simple hypothesis: Neyman-Pearson lemma. Test of a composite hypothesis: family of distributions with monotone likelihood ratio, UMP test for certain one-sided hypothesis concerning a real valued parameter, UMP tests for some two-sided hypothesis in case of one parameter exponential family.

Module II

Unbiased tests, UMPU test, generalization of Neyman-Pearson lemma (statement and applications only), α- similar test and LMP tests (concepts only). likelihood ratio test (LRT), asymptotic properties; LRT for the parameters of normal distributions, connection between tests of hypothesis and confidence sets.

Module III

Sequential methods: Sequential Probability Ratio Test (SPRT), Wald's fundamental identity, OC and ASN functions; Applications to binomial, Poisson and normal distributions.

Module IV

Non parametric tests: Chi-square goodness of fit test, Kolmogorov-Smirnov test (one sample and two sample tests), Sign test, Wilcoxon signed rank test, run test, Wald-Wolfowitz run test, median test, Mann-Whitney Wilcoxon test; Tests for association based on Kendall's Tau and Spearman's rank correlation coefficient. Kruskal –Walli's test, Friedman test.

Text Books:

1. Rohatgi, V. K. and Saleh, A.K.M (2003). An Introduction to Probability and Statistics, John Wiley and Sons.
2. Mukhopadhyay, P. (2006). Mathematical Statistics, Books and Allied (P) Ltd., Kolkatta.
3. Rajagopalan, M. and Dhanavanthan, P. (2012). Statistical Inference, PHI Learning Pvt Ltd, New Delhi.
4. Gibbons, J.D. (1985): Non-Parametric Statistical Inference, 2ndedn. Marcel Dekker Inc.
5. Manoj Kumar Srivastava and Namita Srivastava (2014). Statistical Inference Testing of Hypotheses, PHI Learning Pvt Ltd, New Delhi.

References:

1. Lehmann E.L. (1986): Testing Statistical Hypotheses, 2nd edn. John Wiley & Sons, New York.
2. Ferguson, T.S. (1967). Mathematical Statistics. Academic Press, New York
3. Kendall, M.G. and Stuart, A. (1967). The Advanced Theory of Statistics, vol 2, 2nd edn. Mc-Millan, New York.
4. Shao, J. (2003). Mathematical Statistics, 2n edn. Springer-Verlag, New York.

COURSE CODE : ST 533

COURSE TITLE : MULTIVARIATE ANALYSIS

COURSE OUTCOME

On completion of the course, students should be able to:

CO1: Describe Random vectors, multiple and partial correlation coefficients.
CO2: Describe multivariate normal distribution and its properties.
CO3: Obtain the distributions of quadratic forms in a multivariate random vector.
CO4: Random sampling from a multivariate normal population.
CO5: Obtain the estimators for parameters of a multivariate normal distribution.
CO6: Test the hypothesis regarding parameters of a multivariate normal distribution.
CO7: Test the hypothesis regarding the significant of multiple correlation coefficients.
CO8: Classify individuals/items in to one of k multivariate normal populations.
CO9: Perform principal component analysis and factor analysis

MODULE OUTCOME

MODULE	**Module outcomes** *On completion of each module, students should be able to:*	**Taxonomy Level**
MODULE I	MO1: Describe random vectors and their properties MO2: Define the multivariate normal density function. MO3: Obtain the characteristic function of a multivariate normal density function. MO4: Find the distribution of linear combination of multivariate normal random vector using characteristic function MO5: Characterize quadratic forms of multivariate distribution. MO6: Apply Cochran's theorem to find distribution of quadratic forms of multivariate normal random	Remember Remember Understand Apply Apply Understand

	vector	
MODULE II	MO1: Obtain the MLEs of mean and variance of multivariate normal distribution MO2 : Obtain the characteristic function of Wishart distribution MO3 : Show that Whishart distribution possess additive property MO4 : Find the distribution of sample dispersion matrix	Evaluate Apply Understand Remember
MODULE III	MO1: Test the mean vector of a multivariate normal distribution MO2: Test the equality of means of two multivariate normal distributions MO3: Use Hotelling's T^2 and Mahalanobis D^2 statistics in testing hypothesis regarding multivariate normal distributions. MO4: Find the relationship between Hotelling's T^2 and Mahalanobis D^2 statistics MO5: Find the distribution of sample multiple correlation for multivariate normal distribution	Apply Apply Apply Understand Remember
MODULE IV	MO1: Perform principal component analysis and factor analysis MO2: Classify individuals/items in to one of k multivariate normal populations MO3: Identify canonical variables and quantify canonical correlation MO4: Explain factor analysis and cluster analysis	Analysis Analysis Analysis Apply

COURSE CONTENT

MODULE I

Random vectors, expectation and covariance of random vectors and their properties. Quadratic forms, Characteristic functions in higher dimensions. Multiple correlation and partial correlation (illustrative examples).

Multivariate normal distribution, singular normal distribution, characteristic function. Marginal and conditional distribution, additive property, distribution of linear combination of normal random vectors. Distribution of quadratic forms, Cochran's theorem (statement only).

MODULE II

Random Sampling from multivariate normal distribution, Distribution of sample mean vector, MLE of mean vector and dispersion matrix.

Wishart distribution: definition and properties, analogy with chi-square distribution, characteristic function, additive property, generalized variances, partitioned Wishart matrix, distribution of sample dispersion matrix.

MODULE III

Tests of hypothesis about mean vector of multivariate normal distribution, equality of mean vectors of two multivariate normal distributions- Hoteling's T^2 and Mahalanobis' D^2

Sampling distributions of sample correlation coefficient and multiple correlation coefficient and tests of significance .

MODULE IV

Classification problems: Classifying to one of k multivariate normal populations, Bayes' solution, Fisher's discriminant function, Definition of principal components-extraction of principal components, definition and derivation of canonical variables and canonical correlation, Application of factor analysis and cluster analysis- Orthogonal factor model.

Text Books:

1. Anderson, T.W. (2003). An Introduction to Multivariate Statistical Analysis, John Wiley, New York.
2. Johnson, R.A. and Wichern, D.W. (1992). Applied Multivariate Statistical Analysis, 3rd edn., Prentice- Hall, London.
3. Muirhead, R.J. (1982). Aspects of Multivariate Statistical Theory, John Wiley, New York.

References:

1. Graybill,F.A. (1961). An Introduction to Linear Statistical Model, Vol 1, Mc Graw Hill, New York.
2. Kendall, M.G. (1958). A Course in Multivariate Analysis, Griffin, London.
3. Rohatji, V.K. and Saleh, A.K.M.E. (2003). An Introduction to Probability Theory and Mathematical Statistics, 2nd edn., John Wiley & Sons, New York.
4. Srivastava, M.S. and Khatri, C.G. (1979). An Introduction to Multivariate Statistics, North Holland.

COURSE CODE : ST 534

COURSE TITLE : OPERATIONS RESEARCH

COURSE OUTCOMES

On completion of the course, the students should be able to:

CO1: Describe Simplex method to solve the linear programming problem.
CO2: Explain the steps in solving a linear programming problem by two-phase method.
CO3: Explain the concept of duality in linear programming problem.
CO4: Give the outline of dual simplex method.
CO5: Describe the computational procedure of optimality test in a transportation table.
CO6: Explain the Hungarian method to solve the Assignment problem.
CO7: Give an account of different types of inventory models and inventory cost.
CO8: Derive an EOQ formula for different rate of demand in different cycles.
CO10: Formulate and solve the purchase inventory problem with one price break.
CO11: Derive the steady state solution of M/M/1 queue model.
CO12: Obtain expected number of units in the M/G/1 queueing system under steady state.
CO13: Derive an expression of the average annual cost of an item over a period of n years.
CO14: Describe Bellmen's principle of optimality.

MODULE OUTCOMES

Sl. No:	**Outcomes** On completion of each module, students should be able to:	**Taxonomy Level**
Module I.	M01. Explain the concepts of linear programming problem. M02. Solve the linear programming problem by using Simplex method.	Understand Apply Remember

	M03. Computational steps of Two-phase and Big-M Method M04. Write the dual of the given linear programming problem. M05. Find the initial basic feasible solution to the given Transportation problem. M06. To determine the optimum assignment problem.	Evaluate Evaluate Evaluate
Module: II	M01. Describe the problem of replacement of items whose maintains cost increase with time. M02. Discuss Kuhn-Tucker necessary and sufficient conditions in a non-linear programming problem. M03. Explain Dynamic Programming problem M04. Discuss different models in connection with Dynamic Programming Problem	Understand Evaluate Understand Analysis
Module III	M01. Discuss the characteristics of queueing process M02. Explain the role of Poisson distribution and exponential distribution. M03. Obtain the steady state solution of M/M/1, M/M/C and M/Ek/1 queueing models M04. Discuss Little's Formula M05. Discuss M/G/1 model and Pollaczek-Khintchine formula	Understand Understand Evaluate Apply Understand
Module IV	M01. Explain Inventory control, inventory costs, concept of EOQ, deterministic and probabilistic inventory models. M02. Derive an expression for EOQ for deterministic inventory models with and without shortages M03 Discuss EOQ problem for probabilistic inventory models. M04. Discuss EOQ models with quantity discounts	Understand Apply Apply Evaluate

COURSE CONTENT

MODULE I

Linear Programming Problem: basic feasible solution, graphical method, Standard form of an LPP, Simplex method of solving an LPP, Fundamental Theorem of an LPP, Two-phase method and Big-M method, degeneracy, duality in LPP, Fundamental Theorem of Duality.

Assignment problem, Hungarian method of assignment, transportation problem: basic feasible solution (North-West Corner Method, Least Coast Method and VAM Method) methods of finding optimum solution, degeneracy in transportation problem.

MODULE II

Replacement models: Types of failure, replacement of items deteriorates with time, replacement of items that fail completely.

Non-linear programming: General non-linear programming problems - Constrained optimization with equality and inequality constraints, Kuhn – Tucker conditions (statement only) and applications.

Dynamic programming - Characteristics of dynamic programming problem, different models - Single additive constraint and multiplicative separable return, single additive constraint and additively separable return, single multiplicative constraint and additively separable return, dynamic programming approach for solving a LPP.

MODULE III

Queueing Theory: Characteristics of queueing processes, role of Poisson distribution and exponential distribution in queueing theory, steady state solution of M/M/1 model, Waiting time distribution of M/M/1 model, steady state solution of M/M/C model and steady state solution of M/EK/1 queueing model, measures of effectiveness of these models, Little's Formula, M/G/1 model (description only) and Pollaczek– Khintchine formula.

MODULE IV

Inventory models: Meaning of inventory control, inventory costs, concept of EOQ, deterministic inventory models without shortages - Economic lot size model with constant demand, economic lot size model with different rates of demand in different cycles and economic lot size model with finite replenishment rate. Deterministic inventory models with shortages. Probabilistic inventory models - Single period model without setup cost, single period model with setup cost. The EOQ models with quantity discounts (one price break and two price breaks).

Text Books:

1. Gross, D. and Hariss, C.M. (2009). Fundamentals of Queueing Theory, John Wiley & Sons.
2. Kanthi Swarup, Gupta, P.K, and Man Mohan (2012). Operations Research, Sulthan Chand & Sons.
3. Sharma, J.K. (2009). Operations Research Theory and Applications, Macmillan India Limited

References:

1. Medhi J (2014) Introduction to Queueing Systems and Applications, New Age International Publishers

2. Mittal, K.V. and Mohan, C. (1996). Optimization Methods in Operations Research and System Analysis, New Age Publishers.
3. Paneerselvam, R. (2006). Operations Research, Prentice hall of India.
4. Rao S S. (1984), Optimization Theory and Applications, New Age Publishers, Wiley Eastern.
5. Ravindran, A., Philips, D.T. and Solberg, J. (2007). Operations Research: Principles and Practice, John Wiley & Sons, New York.
6. Taha, H. A. (2010). Operations Research, Macmillan India Limited.

COURSE CODE: ST 535

COURSE TITLE: Elective I - (i) MACHINE LEARNING

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1. Analyze the data and understand the insights from it.

CO2. A clear understanding of machine learning algorithms and

applications. CO3. Apply various ML techniques as per the

requirements

CO4. To acquaint important multivariate

methods

CO5. Apply clustering methods

CO6. Familiarize SVM, neural network, HMM, classification and regression trees

MODULE OUTCOMES

Sl. No:	**Outcomes** **On completion of each module, students should be able to:**	**Taxonomy Level**
MODULE 1.	MO1. Introduction to machine learning and applications MO2. Understanding supervised, unsupervised and reinforcement learning algorithms	Understand Understand

MODULE 2.	MO1: Introduction of Bayesian methods MO2: To get an idea about the parametric inference method MO3: Use of classifications and regression methods	Understand Understand Apply
MODULE 3.	MO1. Understanding various multivariate methods MO2. Introduction to multivariate classification MO3. Apply the concepts of clustering algorithms	Understand , Learning Understand Apply Apply
MODULE 4.	MO1. Understanding of kernel estimation, kNN estimation MO2. Applying classification tree, regression tree, random forest MO3. Real life applications of SVM, naive Bayes and HMM	Understand Understanding and apply Understanding and apply

COURSE CONTENT

MODULE I

Introduction to Machine Learning, its meaning and applications, Outline of Supervised Learning, Unsupervised Learning, Semi Supervised learning, Reinforcement Learning Dimensions of a Supervised Machine Learning Algorithm, Vapnik -Chervonenkis (VC) Dimension, Probably Approximately Correct (PAC) Learning, Noise, Learning Multiple Classes.

MODULE II

Model Selection and generalization, Bayesian decision theory: Introduction, classification, losses and risks, discriminant functions, utility theory, association rules.

Parametric methods: Introduction, Maximum Likelihood Estimation, evaluating an estimator- bias and variance, Bayes' estimator, parametric classification, regression, tuning model complexity: bias/variance dilemma.

MODULE III

Model Selection Procedures, multivariate methods: multivariate data, parameter estimation, concept of imputation, multivariate normal distribution and multivariate methods of classification (concepts only, without any derivation), tuning complexity. Clustering: k means clustering, nearest neighbor method and hierarchical clustering (concept and applications only).

MODULE IV

Basic concepts and applications of: Kernel estimator, kNN estimator, classification tree, regression tree, neural network and random forests, support vector machine, naive Bayes and hidden Markov model (all without any derivation)

Text Books:

1. Alpaydin, E. (2009). Introduction to machine learning. MIT press.
2. Trevor, H., Robert, T., & JH, F. (2009). The elements of statistical learning: data mining, inference, and prediction.
3. Gupta, G.K. (2008): Introduction to Data Mining with case studies, Prentice – Hall of India Pvt. Ltd.

REFERENCES

1. Bhat, B. R. (1985). Modern Probability Theory: An Introductory Text Book, 2nd Edition, Wiley Eastern.
2. Brian Coffo. Statistical Inference for Data Science.
3. Tan, T., Steinbach, M. and Kumar, V. (2006): Introduction to Data Mining, Pearson Education.
4. Daniel T. Larose (2006): Data Mining: Methods and Models, John Wiley and sons. (relevant portions of Chapter 4).

COURSE CODE: ST 535

COURSE TITLE: Elective I- (ii) ORDER STATISTICS

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1. Understand the basic properties of Order statistics.

CO2. Explain Probability mass function of order statistics arising from discrete and distributions.

CO3. Examine order statics of various types of discrete and continuous distributions CO4.Explains the properties and relations of moments of Oder statistics.

CO5. Realize the difference between discrete and continuous probability distributions. CO6. Explain the estimation and prediction under Order statistics.

CO7. Explain the concept of order statistics and solving problems related to it

CO8. Understanding concept of Record value and Concomitant Order statistics and their applications

MODULE OUTCOMES

Sl. No:	**Outcomes** On completion of each module, students should be able to:	**Taxonomy level**
Module I	MO1. Explains the basic concepts of distribution of single order statistic, joint distribution of two or more order statistics. MO2. Verify the Markov property of Order statistics. MO3. Examine the various properties of Order statistics. MO4. . Explain the concept of order statistics	Understand Remember Understand Understand
Module II	MO5. Explain the moments oforder statistic and its properties. MO6. Derive the recurrence relations on the single and product moments of order statistics. MO7. Describe Order statistics from symmetric population.	Understand Remember Understand
Module III	MO1. Examine order statics of various types of discrete and continuous distributions and articulate their properties	Apply
Module IV	MO1. Explain the different estimators used in order statistics MO2.Examine prediction of order statistics. MO3. Find the confidence interval using sample quantile.	Evaluate Apply Understand

COURSE CONTENT

MODULE I

Basic distribution theory: Distribution of single order statistic, joint distribution of two or more order statistics, conditional distributions and Markov chain property. Distribution of median, range and mid-ranges, Probability mass function of order statistics arising from discrete distributions.

MODULE II

Moments of order statistics, Identities on the moments of order statistics, recurrence relations on the single and product moments of order statistics. Discussion of the above relation for symmetric population.

MODULE III

Order statistics from specific population such as Bernoulli and three-point Discrete uniform distribution, exponential distribution, uniform, power function, normal and logistic distributions.

MODULE IV

Order statistics in statistical inference: Order statistics and sufficiency, linear estimations of location and scale parameters, Gupta's simplified linear estimator, prediction of order statistics, confidence intervals using sample quantile.

Text Books

1. Arnold, B. C. and Balakrishnan, N. (1989) : Relations, Bounds and Approximations for order statistics, Lecture notes in Statistics No. 53, Springer- Verlag, New York.
2. Arnold, B. C., Balakrishnan, N. and Nagaraja, H. N. (1992) : A first course in Order Statistics, John Wiley, New York.
3. David, H. A. and Nagaraja, H. N. (2003): Order statistics, 3rd edition, John Wiley, New York.

COURSE CODE: ST 535

COURSE TITLE: Elective I- (iii) BIOSTATISTICS

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1. Understand the concepts about Biostatistics.

CO2. Utilize the fundamental concepts in Epidemiology and its relation with real life situations.

CO3: Familiar with various observational study designs and sample size estimation .

CO4. Get skilled in data modeling through survival analysis of lifetime distributions.

MODULE OUTCOMES

Sl.no	Outcomes On completion of each module, students should be able to	Taxonomy Level
Module I	M01. Explain the importance of Biostatistics in Medicine and Biological sciences M02. Define basic terminologies related to Medical Science.	Understand Evaluate
Module II	M01. Asses validity and reliability of diagonostic and screening test. M02. Explain the use of ROC curve	Understand Apply
Module III	M01. Disclose the basic concepts of Epidemiology M02. Explain the importance of Logistic regression analysis and odds ratio	Understand Analysis

Module IV	M01. Describe the application of survival analysis in medical science by modeling data. M02. Understand the planning and design of clinical trial experiments in different phases.	Apply understand

COURSE CONTENT

Module I

Concepts of Biostatistics: Need for statistical methods in medicine,Public health and Biology. Measuring the occurrence of disease, Measures of morbidity - prevalence and incidence rate, association between prevalence and incidence, uses of prevalence and incidence, problems with incidence and prevalence measurements; Clinical agreement: kappa statistics, Mantel-Haenszel test; intra-class correlation. Study designs- cross sectional, case- control and cohort. Estimation of sample size in different study designs.

Module II

Assessing the validity and reliability of diagnostic and screening test: Validity of screening test –sensitivity, specificity, positive predictive value and negative predictive value; Reliability; Relationship between validity and reliability; ROC curve and its applications,

Module III

Epidemiology concepts: Association; causation; causal inference; Errors and bias; Confounding; Controlling confounding; Measurement of interactions; Estimating risk: Estimating association –absolute risk, relative risk, The Logistic Regression Model, The Logistic Function, Odds Ratio, The Logit of P, Logit Regression Coefficient as measures of effect on Logit P.

Module IV

Survival distributions and their applications viz. Exponential, Gamma, Weibull, Rayleigh, Lognormal, death density function for a distribution having bathtub shape hazard function. Tests of goodness of fit for survival distributions. Parametric methods for comparing two survival distributions -LR test. Planning and design of clinical trials, Phase I, II, and III trials.

Text Books

1.Daniel W. Biostatistics: A foundation for analysis in the health sciences. 10th edition. John Wiley & Sons.

2. P. Armitage, G. Berry & J. N. S. Matthews; 2002; Statistical Methods in Medical Research: 4th Ed., Blackwell science.

3. Martin Bland, 2000 An introduction to medical statistics, Oxford university press.

4. Gross and Clark (1999) Survival distributions: Reliability applications in the Biomedical science: John Wiley & Sons

5. Mark Woodward ,Epidemiology- Study, Design & Analysis:. Chapman & Hall (CRC Series).

References

1. Altman Douglas G (2000). Practical Statistics for Medical Research Chapman & Hall London.

2. Alan J Silman & Gray j Macfarlance (2002), Epidemiological studies a practical guide:, 2nd ed. Camebridge uni press.

3. Cox, D. R. and Oakes, D. (1984): Analysis of survival data, Chapman & Hall, New York.

4. D. Collet (2003), Modeling Survival Data in Medical Research: , CRC Press.

6.Carol Redmond & Theodore colton, 2001, Biostatistics in clinical trials:, John Wiley

7. Fleiss, J. L. (1989). The design and Analysis of Clinical Experiments, John Wiley & Sons.

SEMESTER : 4
COURSE CODE : ST 541
COURSE TITLE : DESIGN AND ANALYSIS OFEXPERIMENTS

COURSE OUTCOME

On completion of the course, students should be able to:
CO1: Identify estimability of a linear parametric function
CO2: Apply Gauss-Markov theorem for finding BLUE of a parametric function
CO3: Understand the methods of model adequacy checking
CO4: Perform one-way and two-way analysis of variances
CO5: Design and analyse CRD, RBD, LSD and GLSD
CO6: Perform analysis of covariance in CRD and RBD
CO7: Perform missing plot and analysis in RBD and LSD
CO8: Construct incomplete block designs
CO9: Analyze BIBD and PBIBD
C10: Design and analyse factorial experiments
C11: Apply principle of total and partial confounding in factorial experiments

MODULE OUTCOME

MODULE	**Module outcomes** *On completion of each module, students should be able to:*	**Taxonomy Level**
MODULE 1	MO1: Identify estimability of a linear parametric function MO2: Apply Gauss-Markov theorem for finding BLUE of a parametric function. MO3: Formulate the model for one way and two way classification MO4: Perform one way and two analysis of variance M05: Understand the methods of model adequacy checking	Understand Apply Understand Analysis Understand
MODULE 1I	MO1: Design and analysis of CRD, RBD, LSD and GLSD MO2: Analysis CRD, RBD and LSD with missing values M03: Perform the analysis of covariance techniques	Analysis Analysis Apply
MODULE III	MO1 : Analyze BIBD with inter and intra block informations MO2: Analyse PBIBD with only two associates classes M03: Construct of BIBD M04: Understand lattice designs	Apply Apply Understand Understand

MODULE IV	MO1: Design and analyse of 2^2, 3^n and p^n factorial experiments MO2: Apply principle of total and partial confounding in factorial experiments M03: Analyze Split-plot M04: Understand the concept of split-split plot and strip-plot designs	Analysis Apply Apply Understan d

COURSE CONTENT

Module I

General linear models, estimable function and conditions for estimability, Principle of least squares, Gauss-Markov theorem, sum of squares, distribution of sum of squares, test of linear hypothesis. Basic principles and planning of experiments, one-way ANOVA and two-way ANOVA, fixed effects and random effect models (concept only), Analysis of fixed effect models, model adequacy checking, Tukey's test of additivity, Duncan's multiple range test.

ModuleII

Completely randomized designs, randomized block designs, latin square design, Graeco latin square design, Analysis with missing values in CRD, RBD and LSD, Analysis of Covariance.

Module III

Incomplete block designs, Balanced incomplete block designs, recovering intra block and inter block information in BIBD, construction of BIBD, PBIBD, Analysis of PBIBD with two associate classes. Lattice designs.

Module IV

Factorial experiments: Testing of significance of factorial effects of 2^2,2^3 and 3^2 experiments, Yates procedure for estimating the effects. Complete confounding, partial confounding. Split plot designs. Concept of split-split plot and strip plot designs.

Text Books:

1. Das, M.N. and Giri, N. (1979). Design and Analysis of Experiments.
2. Montgomery, C.J. (1976). Design and Analysis of Experiments, Wiley Eastern.
3. Joshi, D.D. (1987). Linear Estimation and Design and Analysis of Experiments,Wiley Eastern.
4. Dean, A. and Voss, D. (2006). Design and Analysis of Experiments, Springer.

References:

1. Chakravarthi, M.C. (1962). Mathematics of Design and Analysis of Experiments, Asia Publishing House, Bombay.
2. Hinkelmann, K., Kempthorne, O.(2007). Design and Analysis of Experiments, Volume 1: Introduction to Experimental Design, 2nd Edition, Wiley.
3. Hinkelmann, K., Kempthorne, O.(2005). Design and Analysis of Experiments, Volume 2: Advanced Experimental Design, Wiley.

COURSE CODE: ST 542
COURSE TITLE: STOCHASTIC PROCESSES

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1. Describe and exemplify concepts of Stochastic processes, time space and state space, classification of stochastic processes based on the nature of time space and state space, Classical stochastic processes like processes with stationary independent increments, Markov process, martingales, Wiener process, Gaussian process

CO2. Distinguish between strict and weak (covariance or wide sense) stationarity,

CO3. Explain Markov chains: Definition, transition probability matrix, n-step transition Probability and Chapman-Kolmogorov equation, Calculate n-step transition probabilities, Classify states of a finite Markov chain .

CO4. Describe periodicity and ergodicity of chains, Describe limiting behavior of n-step transition probabilities, obtain the stationary distribution of a Markov chain

CO5. Explain and exemplify continuous time Markov chain, Poisson process, pure birth process, birth and death processes, compound Poisson process, Markov Process with discrete states.

CO6. Explain and exemplify renewal processes, renewal equation. Describe and apply renewal theorem.

CO7. Describe Branching processes, offspring distribution, extinction probabilities

MODULE OUTCOMES

SL. NO	**Outcomes** On completion of each module, students should be able to:	Taxonomy Level
Module I.	M01. Articulate and exemplify the concepts of Stochastic processes, time space and state space. M02. Construction of examples of Stochastic processes M03. Explain the concepts of particular types of stochastic processes like process with stationary independent increments, Markov process, martingales, Wiener process, Gaussian process etc.	Understand Understand Apply
Module II	M01. Articulate concepts of Markov chains, transition probability matrix, n-step transition probabilities M02. Calculate n-step transition probabilities M03. Describe and exemplify classification of states in a Markov Chain M04. Calculate the periodicity of a Markov Chain M05. Explain the concepts of recurrence, ergodic chains M06.Explain and exemplify concepts of limiting behaviour of n-step transition probabilities. M07. Describe stationary distributions and solve problems	Understand Evaluation Understand Evaluation Understand Understand Apply
Module III	M01. Describe and exemplify: Continuous time Markov chains, Poisson process, pure birth process, birth and death processes. M02. Derive of steady state probabilities/differential difference equations in case of Poisson process, pure birth process, birth and death processes. M03. Describe and exemplify: Compound Poisson process, M04 Derive properties of Poisson process and Compound Poisson process M05. Explain the concept of Markov Process with discrete states.	Understand Evaluation Understand Evaluation Understand Apply

	M06. Illustrate these processes with examples	
Module IV.	M01. Describe and exemplify: renewal processes, renewal equation.	Understand
	M02. Explain the statement and applications of renewal theorem	Apply
	M03. Solve problems based on the applications of renewal theorem	Apply
	M04. Concepts of stopping time, Wald's equation, residual and excess life times, backward and forward recurrence times,	Understand
	M05. Poisson process as a renewal process	Analyse
	M06. Describe and exemplify Galton-Watson branching processes	Understand
	M07. Explain concepts of offspring distribution and its implications	Apply
	M08. Interpret the concept of extinction probabilities	Apply
	M09. Compute the probability extinction in case of a particular offspring distribution.	Evaluation

COURSE CONTENT

Module I

Introduction to stochastic processes - time and state space, classification of stochastic processes, processes with independent increments, Stationary processes-definition and examples, Gaussian process, Martingales, Markov process, random walk and Wiener process (examples).

Module II

Markov chain, transition probabilities and stationary transition probabilities, transition probability matrix, Chapman - Kolmogorov equation: classification of states, first passage time distribution, stationary distribution, irreducible Markov chain, aperiodic chain, ergodic theorem and Gamblers ruin problem.

Module III

Poisson process - Properties of Poisson process and related distributions, compound Poisson process, pure birth process, birth immigration process, time dependent Poisson process, pure death process and birth and death process.

Module IV

Renewal process - definition and examples, renewal function and renewal density, renewal equation, statement and applications of renewal theorems, stopping time, Wald's equation, residual and excess life times, backward and forward recurrence times, Poisson process as a renewal process, branching process - definitions and examples, generating function of branching process, Galton - Watson branching process, probability of ultimate extinction, distribution of total number of progeny.

Text books:

1. Karlin, S. and Taylor, H.M. (1975). A First Course in Stochastic Processes, Academic Press.
2. Medhi, J. (2009). Stochastic Processes, New Age International Publishers, New Delhi.
3. Box, G.E.P., Jenkins G.M. and Reinsel, G.C. (2007) Time Series Analysis, Forecasting and Control, Pearson Education.
4. Brockwell,P J. and David R. A. (2002). Introduction to time series and forecasting, 2nd edition, Springer.

References:

1. Bhat, U.N. (1972). Elements of Applied Stochastic Processes, John Wiley, New York
2. Cinlar, E. (1975). Introduction to Stochastic Processes, Prentice Hall, Inc, New York.
3. Makridakis, S and Wheelwright, S C. Forecasting methods and applications, John Wiley and Sons
4. Feller, W. (1968). Introduction to Probability Theory and Applications, Vol. I, John Wiley, New York
5. Feller, W. (1971). Introduction to Probability Theory and Applications, Vol. II, John Wiley, New York

COURSE CODE : 543
COURSE TITLE : REGRESSION METHODS

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1: Describe simple and multiple linear regression models and its assumptions.

CO2: Apply principle of least square method to estimate the parameters in simple and multiple linear regression models.

CO3: Identify multi collinearity problem and its consequences.

CO4: Describe generalized least square method of estimation.

CO5: Understand Residual Analysis and residual plots.

CO6: Explain Generalized Linear models and inference on models with binary response.

CO7: Describe log-linear models for categorical variables.

Module Outcomes

Sl.No	Outcomes On completion of each module, students should be able to	Taxonomy level
Module 1	MO1. Explain simple linear regression model MO2. Describe least square estimators MO3. Articulate to inference regarding regression parameters MO4. Meaning of coefficient of determination.	Understand Remember Apply Analysis
Module II	MO1. Explain multiple linear regression models MO2. Explain inference regarding multiple regression parameters MO3.Methods of Generalized and weighted least squares.	Analysis Understand Apply
Module III	MO1. Different methods of scaling residuals MO2. Residual plots MO3: Detecton of Outliers. MO4. Explain Polynomial regression models MO5. Explain Indicator variables and its usage. MO5. Describe model building strategy MO6: Concept of Stepwise Regressiom. MO7: Problem of multicollinearity	Understand Analysis Understand Understand Understand Apply Apply Understand
Module IV	MO1. Explain Generalized Linear models MO2. Explain models with binary resonse. MO3. Describe link functions MO4: Inference on Poisson regression MO5: Log linear models for categorical data.	Understand Understand Apply Apply Analysis

Course Content

Module I

Identification of Variables, Models, Regression models. Fitting of models- Principle of Least squares, Inference on simple linear regression models. Properties of least square estimators. Significance test and confidence intervals, prediction problems. Coefficient of determination.

Module II
Multiple linear regression models, least square estimation, Properties of least square estimators, hypothesis testing on regression parameters, ANOVA, confidence estimation, prediction of new observations, Generalized and Weighted least squares.

Module III

Residual analysis- Methods of scaling residuals, Residual plots, Partial residual plots, PRESS Statistic.

Polynomial regression, estimation and inference on structural parameters, Indicator variables, uses of Indicator variables, variable selection and model building strategy, All possible regressions, Stepwise regression, Problem of multicollinearity- meaning, sources and consequences.

Module IV

Generalized Linear models, contingency tables, binary response variables- logit models, Log linear models, Logistic regression, Estimation and testing the models, link functions, Poisson regression and its inference.

Logit models for categorical data, Goodness of fit, log linear models for categorical variables (two way contingency table)

Dose response models- quartile response, probit models and median lethal dose.

Text Books:

1. Montgomery, D.C. , Peck, E.A. and Vining, G.G. (2003). Introduction to Linear Regression Analysis, John Wiley & Sons, Asia
2. Rao, C, R. and Tutenburg, H. (1995). Linear Models , Springer Series in Statistics, New York
3. Dobson, A.J. (2002) An Introduction to Generalized Linear models, Second edition, CRC Press.

References:

1. Mc Cullagh, P. and Nelder, J.A. (1989). Generalized Linear Models, Chapman and Hall.
2. Neter, J. and Wasserman, D.W. (1983). Applied Linear Statistical Models, Richard, D. Irwin, Inc., Illinois.
3. Rao, C.R. (1973). Linear Statistical Inference and its Applications, Wiley, New York.
4. Draper, N.R. and Smith, R. (2003). Applied Regression Analysis, John Wiley and Sons inc., New York
5. Seber, G.A.F. (1977). Linear Regression Analysis, John Wiley and Sons, New York

COURSE TITLE: ST 544
COURSE TITLE : Elective II- (i) TIME SERIES ANALYSIS AND FORECASTING

Course Outcomes

On completion of the course, students should be able to:

CO1. Identify, analyze and predict an appropriate model for a given time series data.

CO2. Identify trends, cycles, and seasonal variances and aid in the forecasting of a future event.

CO3. Distinguish between stationary, non stationary time series and other time series models.

CO4. Explain and exemplify the changes associated with the chosen data point compare to shifts in other variables
over the same **time** period.

CO5. Predict future observations and / or estimate unobservable components like trend and seasonal effects.

MODULE OUTCOMES

SL. NO	**Outcomes** On completion of each module, students should be able to:	**Taxonomy Level**
Module I.	M01. Articulate and exemplify the concepts of time series. M02. Construction of examples of various time series data based on trend, seasonality M03. Explain the concepts of additive and multiplicative models, estimation and elimination of the trend and seasonality, exponential and moving average smoothing, holt-winter smoothing, forecasting based on smoothing M04 Analyze the series and detect the presence of the trend and seasonal variation, hence eliminate the presence of the said factors using appropriate methods	Remember and Understand Create Understand Analyze

Module II.	M01. Explain the Stationary time series, Autocorrelation, partial auto correlation function M02. Develop Linear stationary models: auto regressive, moving average and mixed processes. M03.Apply Linear non-stationary models- Autoregressive integrated moving average (ARIMA) models to time series data. M04. Estimate the parameters and forecaste the time series data in the case of ARMA and ARIMA models	Understand Create Understand Apply and Analyze
Module III.	M01.Describe and exemplify the methods of estimation of parameters of the ARMA and ARIMA models. M02. Identify the presence of autocorrelation. M03. Identify and Fit an Auto regressive Process or a Moving Average Process appropriately for a time series data. M04. Estimate the parameters and forecast the time series data in the case of ARMA and ARIMA models.	Remember and Understand Understand Apply Apply and Analyze
Module IV.	M01. Recollect and provide examples for non stationary time series, and seasonal time series models, state space models, ARCH and GARCH models	Remember and Understand Analyze

		Evaluate and Analyze

COURSE CONTENT

MODULE I

Time series, examples and objectives of time series analysis, components of time series, additive and multiplicative models, determination of trend, analysis of seasonal fluctuations, test for trend and seasonality, exponential and moving average smoothing, holt-winter smoothing, forecasting based on smoothing.

MODULE II

Stationary Processes, Some Useful Models, Detailed study of the stationary processes: moving average (MA), autoregressive (AR), Autoregressive Moving Average (ARMA) models and Autoregressive Integrated Moving Average (ARIMA) models.

MODULE III

Estimation of Auto covariance and auto correlation functions, Estimation of parameters of an ARMA model, Estimation of parameters of an ARIMA Model, choice of AR and MA periods, forecasting, residual analysis and diagnostic checking. Regression with ARMA Errors- OLS and GLS Estimation, ML Estimation. Forecasting ARMA and ARIMA models.

MODULE IV

Basic concepts and examples of non stationary and seasonal time series models, state space models, ARCH and GARCH models.

Text Books

1. Brockwell, P. J., & Davis, R. A. (2016). *Introduction to time series and forecasting*. Springer.
2. Chatfield, C. (2009). *The analysis of time series an introduction*. Chapman and Hall/CRC (Sixth Special Indian Edition).

3. Chatfield, C. (2013). *The analysis of time series: theory and practice*. Springer.
4. Montgomery, D. C., Jennings, C. L., &Kulahci, M. (2015). *Introduction to time series analysis and forecasting*. John Wiley & Sons.

Reference

1. Abraham, B., &Ledolter, J. (2009). *Statistical methods for forecasting* (Vol. 234). John Wiley & Sons.
2. Box, G. E., Jenkins, G. M., Reinsel, G. C., &Ljung, G. M. (2015). *Time series analysis: forecasting and control*. John Wiley & Sons.
3. Brockwell, P. J., Davis, R. A., & Fienberg, S. E. (1991). *Time series: theory and methods: theory and methods*. Springer Science & Business Media.
4. Chatfield, C., & Xing, H. (2019). *The analysis of time series: an introduction with R*. CRC press.
5. Cryer, J. D., & Chan, K. S. (2008). *Time series analysis: with applications in R*. Springer Science & Business Media.
6. Jonathan, D. C., & Kung-Sik, C. (2008). Time series analysis with applications in R. *SpringerLink, Springer eBooks*.
7. Faouzi, J., &Janati, H. (2020). pyts: A Python Package for Time Series Classification. *Journal of Machine Learning Research*, *21*(46), 1-6.
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14. Wei, W. W. (2018). *Multivariate time series analysis and applications*. John Wiley & Sons.

COURSE TITLE: ST 544
COURSE TITLE : Elective II- (ii) BAYESIAN INFERENCE

COURSE OUTCOMES
On completion of the course, students should be able to:
CO1. Use relative frequencies to estimate probabilities.

CO2. Calculate conditional probabilities
CO3. Calculate posterior probabilities using Bayes' theorem.
CO4. Calculate simple likelihood functions

MODULE OUTCOMES

MODULE	**Module outcomes** *On completion of each module, students should be able to:*	**Taxonomy Level**
MODULE 1	M01. Explain prior distribution M02.Interpret Bayes theorem and articulate to find posterior distribution.checking	Understand Apply
MODULE 1I	M01. Find conjugate family of prior for a model M02. Choose appropriate member of conjugate prior for a family MO3. Explain non-informative, improper and invariant priors MO4. Define Jeffrey's invariant prior	Analysis Analysis Apply Understand
MODULE III	MO1. Explain different types of loss function. MO2. Evaluate the estimate in terms of posterior risk	Apply Apply
MODULE IV	MO1. Explain Bayesian interval estimation MO2. Explain highest posterior density regions MO3. Interpret confidence coefficient of an interval and its comparison with the interpretation of the confidence coefficient for a classical confidence interval	Analysis Apply Evaluate Understand

COURSE CONTENT

MODULE I: Subjective interpretation of probability in terms of fair odds. Evaluation of (i) subjective probability of an event using a subjectively unbiased coin (ii) subjective prior distribution of a parameter. Bayes theorem and computation of the posterior distribution.

MODULE II: Natural Conjugate family of priors for a model. Hyper parameters of a prior from conjugate family. Conjugate families for (i) exponential family models, (ii) models admitting sufficient statistics of fixed dimension. Enlarging the natural conjugate family by (i) enlarging hyper parameter space (ii) mixtures from conjugate family, choosing an appropriate member of conjugate prior family. Non-informative, improper and invariant priors. Jeffrey's invariant prior.

MODULE III: Bayesian point estimation: as a prediction problem from posterior distribution. Bayes estimators for (i) absolute error loss (ii) squared error loss (iii) 0 - 1 loss. Generalization to convex loss functions. Evaluation of the estimate in terms of the posterior risk.

MODULE IV: Bayesian interval estimation: Credible intervals. Highest posterior density regions. Interpretation of the confidence coefficient of an interval and its comparison with the interpretation of the confidence coefficient for a classical confidence interval.

REFERENCES

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Bernando, J. M. and Smith, A. F. M. (1994): Bayesian Theory, Jolm Wiley and Sons.

DeGroot, M. H. (1970): Optimal Statistical Decisions, McGraw Hill.

Gemerman, D. (1997): Markov Chain Monte Carlo Stochastic Simulation for Bayesian Inference, Chapman Hall.

Leonard, T. and Hsu, J. S. J. (1999): Bayesian Methods, Cambridge University Press.

Robert, C. P. (1994): The Bayesian Choice: A decision Theoretic Motivation, Springer.

COURSE TITLE: ST 544
COURSE TITLE : Elective II- (iii) ACTUARIAL STATISTICS

COURSE OUTCOMES

On completion of the course, students should be able to:

CO1. Develop a greater understanding of statistical principles and their application in
actuarial statistics.

CO2. Describe the core areas of actuarial practice and relate to those areas actuarial principles, theories and models.

CO3. Describe estimation procedures for lifetime distributions. CO4 Explain the concept of survival models.

CO5. Understand the application of knowledge of the life insurance environment.

CO6. Describe Net premiums and its various types.

CO7. Expand their applied knowledge in various specialized areas of actuarial studies and statistics.

MODULE OUTCOMES

Sl. No:	**Outcomes** On completion of each module, students should be able to:	**Taxonomy level**
MODULE 1	MO1. Explains the utility theory and insurance. MO2. Explain survival function and application. MO3. Examine the properties of force of mortality. MO4 Define Life tables and its relation with rvival function, examples. MO5.Explain Multiple life functions and its properties. MO6. Articulate the insurance and annuity benefits through multiple life functions evaluation for special mortality laws. MO7. Explains the Multiple decrement tables. MO8.Describe net single premiums and their numerical Evaluations	Understand Understand Apply Remember Understand Analysis Understand Remember
MODULE II	MO1.Define Distribution of aggregate claims . MO2. Derive the compound Poisson distribution and explain its applications. MO3. Explain Principles of compound interest and its attributes.	Understand Remember Understand

MODULE III	MO1. Explain the Life insurance and its types. MO2 : Describe Insurance payable at the moment of death and at the end of the year of death-level benefit insurance MO3. Explain the Life annuities and its types.	Understand Analysis Understand
MODULE IV	MO1. Explain Net premiums and its importance MO2. Distinguish between Continuous and discrete premiums MO3. Accumulation type benefits.	Understand Analysis Apply

COURSE CONTENT

MODULE I

Utility theory, insurance and utility theory, models for individual claims and theirnsums, survival function, curtate future lifetime, force of mortality. Life tables and its relation with survival function, examples, assumptions for fractional ages, some analytical laws of mortality, select and ultimate tables.

Multiple life functions, joint life and last survivor status, insurance and annuity benefits through multiple life functions evaluation for special mortality laws. Multiple decrement tables, central rates of multiples decrement, net single premiums and their numerical evaluations.

MODULE II

Distribution of aggregate claims, compound Poisson distribution and its applications. Principles of compound interest: Nominal and effective rates of interest and discount, force of interest and discount, compound interest, accumulation factor, continuous compounding.

MODULE III

Life insurance: Insurance payable at the moment of death and at the end of the year of death-level benefit insurance, endowment insurance, differed insurance and varying benefit insurance, recursions, commutation functions. Life annuities: Single payment, continuous life annuities, discrete life annuities, life annuities with monthly payments, commutation functions, varying annuities, recursions, complete annuities immediate and apportion able annuities-due.

MODULE IV

Net premiums: Continuous and discrete premiums, true monthly payment premiums, apportion able premiums, commutation functions, accumulation type benefits. payment premiums, apportion able premiums, commutation functions, accumulation type benefits.

TEXT BOOKS

1. Beard, R.E., Penlikainen, T. and Pesonnen, E (1984): Risk Theory: The Stochastic Basis of Insurance, 3rd Edition, Chapman and Hall, Londan.
2. Bowers, N.L., Gerber, H.U., Hickman, J.E., Jones, D.A. and Nesbitt, C.J. (1997): ' Actuarial Mathematics', Society of Actuarias, Ithaca, Illiois, U.S.A., second Edition.
3. Neill, A. (1977): Life Contingencies, Heineman.

COURSE CODE: ST 545
COURSE TITLE: PRACTICAL II USING R

Topics cover ST 533, ST 541, ST 543 and ST 544.