**University of Pune**

**Two Year M. A. / M. Sc. Degree Program in Statistics**

**Revised Syllabi of M. A. / M. Sc. in Statistics (Credit System)**

**(To be implemented in the Department of Statistics, University of Pune)**

**(With effect from Academic Year 2013-2014)**

Submitted by

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Chairperson,
Board of Studies in Statistics

**1. Title of the course:** M. A. / M. Sc. in Statistics

**2. Preamble of the syllabus:** M. A. / M. Sc. Statistics programme is of minimum 100 credits spread over four semesters. This program is offered at the Department of Statistics, University of Pune. The programme emphasizes both theory and applications of statistics and is structured to provide knowledge and skills in depth necessary for the employability of students in industry, other organizations, as well as in academics. The program has some unique features such as independent projects, a large number of elective courses, pre-requisite system and extensive computer training of statistical computations including standard software packages such as MATHEMATICA, MATLAB, MINITAB, R, S-PLUS, GAUSS and SYSTAT. The department has the academic autonomy and it has been utilized to add the new and need based elective courses. In the past courses such as *Time Series Analysis, Survival Analysis, Reliability, Actuarial Statistics, Multiple Decrement Models in Insurance, Stochastic Models in Finance, Data Mining, Statistical Analysis of Clinical Trials, Statistical Analysis of Microarray Data, Analysis of Longitudinal Data, Frailty models, Statistical Bio-Computing and Natural Language Processing* have been introduced. The independent project work is one of the important components of this program. The syllabus of the first year (two semesters) covers most of the core courses. In the second year syllabus there are five core courses and five optional courses. The syllabus has been framed to have a good balance of theory, methods and applications of statistics.
It is possible for the students to study basic courses from other disciplines such as economics, life sciences, computer science, mathematics in place of electives.

**3. Introduction:** M. A. / M. Sc. Statistics program has semester pattern and credit system with variable credits. The program consists of 100 credits. Credits of a course are specified against the title of the course. A course with T in brackets indicates that it is a theory course whereas a course with P in brackets indicates that it is a practical course. Some of the practical courses are linked with a theory course and in such a case, both the courses will have the same number with T and P, indicating a theory and a practical course respectively. A student can enroll for a practical course if

(i) the student has enrolled for the corresponding theory course (as indicated) in the same term

or

(ii) the student has passed the corresponding theory course in an earlier term

or

(iii) terms for the corresponding theory course have been granted in an earlier term.

The programme has pre-requisites system. Under this system, a student has to clear pre-requisite courses to take up some courses in following semesters.

Unless a student passes the pre-requisites of a course, (s)he will not be allowed to enroll in the said theory courses. Pre-requisites of a course are indicated in curly brackets against the course. The Departmental committee may change the pre-requisites of a course.

**4. Eligibility:** For M. A. in Statistics following candidates are eligible.

(i) B. A. (Second class) with Statistics as principal and Mathematics at subsidiary level,
(ii) B. A. (Second class) with Mathematics as principal and Statistics at subsidiary level,
(iii) M. A. (Second class) in Mathematics
(iv) B. A. (Second class) in Actuarial Science with Mathematics and Statistics at subsidiary level,
(v) B. A. (Second class), with three subjects at third year with Statistics as one of the subjects.

For M. Sc. in Statistics following candidates are eligible.

(i) B.Sc. (Second class) with Statistics as principal and Mathematics at subsidiary level,
(ii) B.Sc. (Second class) with Mathematics as principal and Statistics at subsidiary level,
(iii) M.Sc. (Second class) in Mathematics,
(iv) B.Sc. (Second class) in Actuarial Science with Mathematics and Statistics at subsidiary level,
(v) B.Sc. (Second class), with three subjects at third year with Statistics as one of the subjects.

**5. Examination**

A) (i) Pattern of examination: There would be continuous internal assessment (CIA) and an end of term examination (ETE) for each course. Both CIA and ETE have 50% weightage. The CIA includes class tests, assignments, viva-voce and presentations. There would be assignments or minor projects for some of the elective courses in ETE also.

(ii) Pattern of the question paper: For a theory course with 4 credits, duration for the ETE will be three hours. For a theory course with 3 credits, duration for the ETE will two and half hours, for a theory course with 2 credits, duration for the ETE will two hours and for a practical course with 2/3 credits, duration for the ETE will be 2 hours

B) Standard of passing: A student has to obtain 40% marks in the combined grading of the ETE and the CIA for passing the course, with a minimum passing of 30% in both CIA and ETE separately.

C) ATKT rules: A student can register for the third semester, if (s)he completes 50% credits of the total credits expected to be completed within first two semesters, subject to the pre-requisite system mentioned above. Once registered, a student must complete M. A. / M. Sc. within a period as specified by the University.

D) Award of class: As per the University rules.

E) External students: Not applicable

F) Setting of question paper: The Department has been given autonomy for setting the question papers and grading the answer papers. A teacher teaching a course sets the question paper of the course and assesses the answer books. Question papers are moderated by a committee of subject experts from other universities after a preliminary round of internal moderation.

G) Verification or revaluation: As per the University rules

**6. Structure of the course**

**(a) Compulsory papers**

Compulsory courses in semester I and semester II are listed below.

**Semester I**

ST 1 Mathematical Analysis (4)
ST 2 (T) Linear Algebra (3)
ST 2 (P) Linear Algebra (2)
ST 3 Univariate Probability Distributions (2)
ST 4 Multivariate Probability Distributions (4)
ST 5 (T) Elements of Statistical Computing (4)
ST 5 (P) Elements of Statistical Computing (3)
ST 6 Calculus (4)

Total credits 26

**Semester II**

ST 7 Probability theory (4) {ST 1, ST 6}
ST 8 Limit Theorems in Probability (2) {ST 1, ST 6}
ST 9 (T) Multivariate Analysis (4) { ST 2 (T), ST 3, ST 4, ST 6}
ST 9 (P) Multivariate Analysis (2) { ST 2 (T), ST 3, ST 4, ST 6}
ST 10 Statistical Inference (3) {ST 3, ST 4}
ST 11 Testing of Hypotheses (3) {ST 3, ST 4}
ST 12 (T) Regression Analysis (4) {ST 2 (T), ST 3, ST 4}
ST 12 (P) Regression Analysis (2) {ST 2 (T), ST 3, ST 4}

Total credits 24

In semesters III and IV some courses are compulsory and some are optional. List of optional courses is given in 6(b).

**Semester III**

ST 13 Stochastic Processes (4)
ST 14 (T) Asymptotic Inference (4) {ST 7, ST 8, ST 10, ST 11}
ST 14 (P) Asymptotic Inference (2) {ST 7, ST 8, ST 10, ST 11}
ST 15 (T) Design of Experiments and Analysis of Variance (4) {ST 12(T)}
ST 15 (P) Design of Experiments and Analysis of Variance (2) {ST 12(T)}
Optional course I (4)
Optional course II (4)

Total credits 24

**Semester IV**

ST 16 (T) Sampling Methods (4)
ST 16 (P) Sampling Methods (2)
ST 17 Bayesian Inference (4) { ST 10, ST 11}
ST 18 (P) Project (4) {ST 9 (T), ST 12 (T) }
Optional course III (4)
Optional course IV (4)
Optional course V (4)

Total credits 26

The compulsory courses in all the semesters are the core courses. These have 80 (61 (theory) + 15 (practical) + 4 (project)) credits in all. There are five elective courses having 20 credits.

A student may be allotted a module by the Department at the beginning of the second year of the program. The allotment is based on the performance of student as indicated by her/his rank among all the students given admission in the same year. A total of 12 credits should be obtained from the courses listed as module specific courses. The remaining 8 credits need to be obtained from the optional courses listed in 6(b) or from courses from other departments, as allowed by the University. Departmental committee may allow a student to complete M.A./M.Sc. without any specific module.

A student can opt for a theoretical project in lieu of an optional course or two optional courses with the permission of the Head of the Department. A copy of rules and regulations regarding completion and submission of the project work by a student and assessment of the project work is available in the Department.

Below is given a list of 5 modules. Courses specific to a given module are also listed. Each of these courses, called as a module-specific course, has 4 credits.

A project can have either 4 credits or 8 credits. A project with 4 credits has to be completed within a semester. A project with 8credits will be spread over two

semesters; work in each semester is to be counted for 4 credits. A student can opt for two different projects also, each having 4 credits.

**Modules**

M1. Probability and Mathematical Statistics
M2. Industrial Statistics
M3. Financial and Actuarial Statistics
M4. Bio-Statistics
M5. Computational Statistics

**List of module specific courses**

**Module 1: Probability & Mathematical Statistics (M1)**
ST P1 Measure Theory and Probability {ST 7, ST 8}
ST P2 Advanced Stochastic Processes {ST 7, ST 8, ST 13}
ST P3 Inference in Stochastic Processes {ST 13, ST 14 (T)}
ST P4 Advanced Probability {ST 7, ST 8}
ST P5 Advanced Inference {ST 10, ST 11}

**Module 2: Industrial Statistics (M2)**
ST I1 Optimization Techniques {ST 2 (T)}
ST I2 Statistical Methods for Quality Control {ST 3, ST 4}
ST I3 Reliability Theory {ST 3, ST 4}
ST I4 Time Series Analysis {ST 12 (T)}
ST I5 Stochastic Models in Queues and Inventories {ST 13}

**Module 3: Financial and Actuarial Statistics (M3)**
ST F1 Actuarial Statistics {ST 3, ST 4}
ST F2 Time Series Analysis {ST 12 (T)}
ST F3 Stochastic Models in Finance {ST 13}
ST F4 Survival Analysis {ST 14 (T)}
ST F5 Multiple Decrement Models in Insurance {ST F1}

**Module 4: Bio-Statistics (M4)**
ST B1 Survival Analysis {ST 14 (T)}
ST B2 Analysis of Clinical Trials {ST 12 (T), ST 15 (T)}
ST B3 Medical and Health Statistics {ST 3, ST 4}
ST B4 Statistical Methods in Micro-array Data Analysis {ST 9 (T)}
ST B5 Population Growth Models {ST 3, ST 4, ST 10, ST 11}
ST B6 Statistical Methods for Bio-computing {ST 5 (T), ST 13}

**Module 5: Computational Statistics (M5)**
ST C1 Statistical Simulations {ST 3, ST 4, ST 5 (T)}
ST C2 Computer-Intensive Statistical Methods {ST 5 (T)}
ST C3 Bayesian Computing {ST 5 (T)}
ST C4 Statistical Learning and Data Mining {ST 9 (T), ST 12 (T)}

ST C5 Statistics in Natural Language Processing {ST 3, ST 4}
ST C6 Statistical Methods for Bio-computing {ST 5 (T), ST 13}

The Departmental committee may decide (i) not to offer modules if sufficient faculty is not available and (ii) to offer two modules, where courses from these five modules will be merged.

**(b) Optional papers:** (Depending on the availability of faculty elective courses will be offered from the following list.) A student may choose optional courses from the courses which are listed as compulsory for a module other than the module allotted to her/him or from courses offered by other Departments subject to the approval of the Head of the Department. A student may opt for a project (or two projects) in lieu of an optional (or two optional courses), as described earlier.

**List of Proposed Optional Courses**

ST E01 Stochastic Models {ST 3, ST 4, ST 13}
ST E02 Empirical Processes {ST 7, ST 8, ST 13}
ST E03 Sequential Analysis {ST 10, ST 11}
ST E04 Nonparametric Inference {ST 10, ST 11}
ST E05 Discrete Data Analysis {ST 14 (T)}
ST E06 Stochastic Models in Epidemiology {ST 3, ST 4, ST 13}
ST E07 Advanced Time Series {ST I4 / ST F2}
ST E08 Longitudinal Data Analysis {ST 12 (T)}
ST E9 Financial Econometrics {ST I4 / ST F2}
ST E10 Directional Data Analysis {ST 9 (T)}
ST E11 Total Quality Management and Six Sigma {ST I2}
ST E12 Statistics in General Insurance {ST 3, ST 4}
ST E13 Generalized Linear Models {ST 12 (T)}
ST E14 Frailty Models {ST 14 (T)}

The Head of the Department may introduce additional optional courses on recommendations of the Departmental Committee. The syllabus of the optional courses will be prepared by the concerned teacher and will be flexible to accommodate new developments in that area. Whenever such an optional course is floated, the concerned syllabus will be discussed and approved in the Departmental committee.

**(c) (i) Question papers:** In view of academic autonomy given to the Department, question papers are set by the teacher who teaches the course and these are moderated by a committee of experts, as indicated earlier.

**(ii) Medium of instructions:** English

**7) Equivalence:** The Head will take the decisions as and when the case arises.

**8) University Terms:** Time table for the beginning and end of the terms as announced by the University will be followed.

**11) Qualification of Teacher:** As per the University rules.

**9) and 10) Subject wise detailed syllabus and recommended books:** Detailed syllabi, along with the list of recommended books of the compulsory courses in the first year of M.Sc. are given below.

***L**: Lectures; **T**: Tutorials.*

*Tutorial session is equivalent to one Lecture wherein the students are expected to solve pre-circulated problems on specified topics.*

**ST 1: Mathematical Analysis (4 credits)**

**Unit I**

Countability, supremum and infimum of sets of real numbers. Archimedean property, denseness property of rationals. Metric spaces, limit points and interior points of a set, open sets, closed sets etc. (These concepts will be introduced through metric spaces and $R^n$ will be considered as a special case). **(12L + 3T)**

**Unit II**

Compactness, Bolzano-Weierstrass theorem, Heine-Borel Theorem. Sequences of real numbers, Cauchy sequence, limit superior, limit inferior, limit and convergence of a sequence of real numbers. Cauchy criterion for convergence. Completeness of R.

**(12L + 3T)**

**Unit III**

Series of real numbers, convergence of series, tests for convergence of series, absolute convergence, Cauchy product of two series and its convergence. Power series and radius of convergence, examples and problems on these concepts. **(12L + 3T)**

**Unit IV**

Continuous functions, uniform continuity, uniform convergence of sequences and series of functions, term by term differentiation and integration, applications to power series. **(12L + 3T)**

**Total (48L + 12T)**

**Books Recommended**

1. Apostol, T. M. (1975). Mathematical Analysis: A Modern Approach to Advanced Calculus. (Addison - Wesley)
2. Bartle R. G. & Sherbert D. R., (2007), Introduction to Real Analysis (Wiley
3. Bartle, R. G. (1976). Elements of Real Analysis (John Wiley)

4. Goldberg R. R. (1976). Methods of Real Analysis, (John Wiley & Sons, Inc.)
5. Rudin, W. (1985). Principles of Mathematical Analysis (McGraw - Hill) Student Edition)
6. Trench W. F. (2012). Introduction to Real Analysis. E-book.

**ST 2 (T): Linear Algebra (3 credits)**

**Unit I**

Determinants and their simple properties, inverses of partitioned matrices, special types of matrices, orthogonal and idempotent matrices, quadratic forms, vector spaces, inner product of vector spaces, linear dependence and linear independence of vectors, bases, an orthogonal basis, basis and dimension, properties and uses of a basis. **(12L + 3T)**

**Unit II**

Linear transformation and their matrix representations, rank of a matrix, linear equations, solution space and null space, generalized inverse, echelon forms, canonical forms, Gram-Schmidt orthogonalization, projection theorem. **(12L + 3T)**

**Unit III**

Characteristic roots of real matrices, right and left characteristic vectors, linear independence of characteristic vectors corresponding to distinct characteristic roots, algebraic and geometric multiplicities, spectral decomposition theorem, Cayley-Hamilton theorem. Definiteness of a real quadratic form, reduction of quadratic forms, simultaneous reduction of two quadratic forms, maxima and minima of ratios of two quadratic forms. **(12L + 3T)**

**Total (36L + 9T)**

**Books Recommended**

1. Bapat, R.B. (2011). Linear Algebra and Linear Models. Springer and Hindustan Book Agency
2. Bellman, R. (1970). Introduction to Matrix Analysis. (Tata McGraw Hill)
3. Graybill, F.E. (1961). Introduction to Matrices with Applications in Statistics (Wadsworth Pub. Co.)
4. Hohn, F. E. (1973). Elements of Matrix Algebra (Macmillan)
5. Ramachandra Rao, A. and Bhimasankaram, P. (2000). Linear Algebra. (Hindustan Book Agency)
6. Rao, C. R. (1995). Linear Statistical Inference and Its Applications. (Wiley Eastern)
7. Sadun L. (2008): Applied Linear Algebra: The Decoupling Principle. (American Mathematical Society) Second Edition.
8. Searle, S. R. (1982). Matrix Algebra Useful for Statistics. (John Wiley)

**Additional Reference:**

http://aix1.uottawa.ca/~jkhoury/app.htm

**ST 2 (P): Linear Algebra Practical (2 credits)**
Software such as R, SYSTAT, MATLAB etc will be used.

**Unit I**
1. Calculation of determinant of higher order by partitioning method.
2. Calculation of a rank of a matrix.
3. Calculation of equivalence canonical form by using elementary row and column operations.
4..Calculation of inverses of symmetric matrices of higher order by partitioning method.
5. Calculation of inverse of matrices of higher order.

**Unit II**
1. Calculation of Moore-Penrose inverse.
2. Calculation of a g- inverse.
3. Calculation of eigen values, eigen vectors,
4. Solution of simultaneous equations.
5. Spectral decomposition and powers of a matrix

**ST 3: Univariate Probability Distributions (2 credits)**

**Unit I**

Review of the concept of a random variable, c.d.f, characteristic properties of c.d.f. p.d.f., p.m.f., absolutely continuous and discrete distributions, m.g.f., p.g.f., quantiles and symmetry of a distribution, Stieltjes moment problem. Mixtures of probability distributions, decomposition of a c.d.f. into discrete and continuous c.d.f.s.

**(12L+3T)**

**Unit II**

Brief review of standard discrete and continuous distributions, truncated distributions (truncated binomial, truncated Poisson, truncated normal etc.)
Concept of hazard rate and cumulative hazard rates. Introduction to IFR, DFR, IFRA and DFRA classes of distributions. Transformations (monotone, non-monotone) of random variables and their distributions

**(12L+3T)**

**ST 4: Multivariate Probability Distributions (4 credits)**

**Unit I**

Random vectors, joint distributions, joint m.g.f., joint p.g.f., mixed moments, variance-covariance matrix, multivariate Normal and bivariate exponential distributions. **(12L + 3T)**

**Unit II**

Independence of random variables, sums of independent random variables, convolutions, conditional expectation and variances, compound distribution.

Regression function, best predictor, best linear predictor, multiple and partial correlation coefficients. **(12L + 3T)**

**Unit III**

Sampling distributions of statistics from univariate normal random samples, such as linear and quadratic forms, Fisher Cochran theorem, non-central $\chi^2$, non central t and F distributions.

**(12L + 3T)**

**Unit IV**

Order statistics: Probability Integral transformation, joint distribution of order statistic, distribution of r-th order statistic, joint distribution of $r^{th}$ and $s^{th}$ order statistics ($r < s$) and their functions, distribution of spacings, normalized spacings with illustration to exponential case, distribution of sample range.

**(12L + 3T)**

**Total (48L + 12T)**

**Books Recommended**


1. Berger, R. and Casella G. (2002) Statistical Inference (Duxbury Resource Center) Second Edition.
2. Cramer H., (1946) Mathematical Methods of Statistics (Springer).
3. Dasgupta, A. (2010) Fundamentals of Probability: A First Course (Springer)
4. Hogg, R. V. and Craig, T. T. (1978) Introduction to Mathematical Statistics (Collier-McMillan) Fourth Edition
5. Rao B.L.S. P. (2009). A First course in probability and Statistics, (World
6. Rao, C. R. (1995) Linear Statistical Inference and Its Applications (Wiley Eastern) Second Edition
7. Rohatgi, V. K. (1988) Introduction to Probability Theory and Mathematical Statistics (Wiley Eastern Scientific, Singapore)


**ST 5 (T): Elements of Statistical Computing (4 Credits)**

**Unit I**

Random number generation. Requisites of a good random number generator, methods of random number generation such as linear congruential, mixed congruential and multiplicative congruential. Testing of random number generator, run test, Kolmogrov-Smirnov test, sign test, rank test, gap test, digit frequency test and serial correlation, selection of a random number generator. Methods of generating random variables such as inverse transforms, composition, convolution and acceptance –rejection. **(12L+3T)**

**Unit II**

Simple optimization method, direct search, grid search, interpolatory search, gradient search. Newton-Raphson method, Muller's method, Aitken's extrapolation. Simple problems, case studies and applications to bacterial chemostat, industrial high temperature oven etc.

**(12L+3T)**

**Unit III**

Methods to compute integrals: quadrature formula, double integration, singularity, Gaussian integration. Monte Carlo Methods: Monte Carlo integration and Simple case studies, applications of Monte Carlo methods to compute expected values of functions of random variables, such as Laplace transform, fourier transform etc. Case studies such as change in entropy, R-C network.

**(12L+3T)**

**Unit IV**

Approximating probabilities and percentage points in selected probability distribution, verification of WLLN and CLT using random number generator, simulating null distribution of various test statistics. simple applications and case studies. **(12L+3T)**

**Total (48 L+ 12T)**

**Books Recommended:**


1. Kennedy W. J. & Gentle J. E. (1980). Statistical Computing (Marcel Dekker)
2. Krishnamurthy V. & Sen (1993). Numerical Algorithm Computation in Science and Engineering. (Affiliated East West Press), Second edition
3. Law, A.M. and Kelton, W.D. (2000). Simulation, Modeling and Analysis Third Edition. (Tata McGraw Hill)
4. Rajaraman V. (1993). Computer Oriented Numerical Methods, (Prentice-Hall). Fourth edition
5. Ripley B. D.(1987) Stochastic Simulation. (John Wiley)
6. Ross, S. (2000). Introduction to Probability Models. (Academic Press)
7. Schilling, R.J. and Harris, S.L.(2002). Applied Numerical Methods for Engineers Using MATLAB and C, (Thomson and Brooks/Cole, Singpore)
8. Thisted R. A.(1988). Elements of Statistical Computing, (Chapman and Hall)


**ST 5 (P): Elements of Statistical Computing Practical (3 Credits)**

Elementary Statistics as listed below using software packages: SYSTAT, R, MINITAB, $S^+$, MATLAB, MATHEMATICA

**Unit I**

1. Computation of integrals by Riemann & RS sums.

2. Calculation of double integrals.
3. Calculation of p-value for standard tests of hypotheses.
4. Plotting of curves (standard & non standard), Box Plot, Q-Q plot

**Unit II**

1. Limits of functions
2. Computing integrals by statistical methods
3. Computing expectations of complicated functions, mean and variance of estimators
4. Empirical level of significance and empirical power
5. Empirical confidence coefficient of a confidence interval

**Unit III**

1. Test for randomness, Sign test, Kolmogrov-Smirnov test, Wilcoxon signed rank test.
2. Iterative solution of a function using Newton-Raphson method, Muller's method.
3. Verification of WLLN for i.i.d. random variables.
4. Verification of CLT for i.i.d. random variables.

**Books Recommended:**


1. Boswell, M.T., Gore, S.D., Patil G. P. and Tallie C. (1993). Handbook of Statistics - Vol 4 (The Art of Computer Generation of Random Variables)
2. Kennedy W. J. & Gentle J. E. (1980). Statistical Computing (Marcel Dekker)
3. Krishnamurthy V. & Sen (1993). Numerical Agorithm Computation in Science and Engineering 2ndEd. (Affiliated East West Press)
4. Purohit, S.G. ,Gore, S.D. and Deshmukh, S.R., (2008): Statistics using R: Narosa Publications
5. Rajaraman V. (1993). Computer Oriented Numerical Methods, (Prentice-Hall). Fourth Edition.
6. Ripley B. D. (1987). Stochastic Simulation (Wiley)
7. Ross, S. (2000). Introduction to Probability Models.(Academic Press)
8. Thisted R. A.(1988). Elements of Statistical Computing, (Chapman and Hall)


**ST 6: Calculus (4 credits)**

**Unit I**

Review of calculus of one variable: differentiability, mean value theorem and Taylor series expansion. Functions of several variables: Continuity, directional derivatives, differentials of functions of several variables, the gradient vector

**(12L+3T)**

**Unit II**

Differentials of composite functions and the chain rule, the mean value theorem, a sufficient condition for the existence of the differential, partial derivatives of higher order and Taylor's formula. Applications of partial

differentiation, Jacobians. **(12L+3T)**

**Unit III**

Inverse function theorem (without proof), implicit function theorem (without proof), extremum problems. Riemann and Riemann–Stieltjes integrals, integration by parts, mean value theorem. **(12L+3T)**

**Unit IV**

Improper Riemann – Stieltjes integrals: Improper integrals of first and second kind for one variable. Uniform convergence of improper integrals, differentiation under the sign of integral – Leibnitz rule. Multiple Integrals and evaluation of multiple integrals by repeated integration. Mean value theorem for multiple integrals. (12L+3T)

**Total (48 L+ 12T)**

**Books Recommended**


1. Apostol T.M. (1975). Mathematical Analysis: A modern approach to advanced calculus. (Addison-Wesley)
2. Bartle, R. G. (1976). Elements of Real Analysis. (John Wiley)
3. Kreyszig, E. (1975). Advanced Engineering Mathematics (Wiley Eastern)
4. Rudin, W. (1985). Principles of Mathematical Analysis (McGraw-Hill)
5. Trench W. F. (2012). Introduction to Real Analysis. E-book


**ST 7: Probability Theory (4 credits)**

**Unit I**

Classes of sets, fields and sigma-fields, limit of sequences of subsets, sigma-field generated by a class of subsets, Borel fields. Probability measure on a sigma-field, probability space, continuity of a probability measure. Real and vector-valued random variables (r.v.s). **(12L+3T)**

**Unit II**

Distribution functions (d.f.), discrete r.v.s, r.v.s of the continuous type, decomposition of a d.f. Expectation of a real r.v. Linear properties of expectations, Inequalities, Characteristic functions, their simple properties, uniqueness theorem (without proof). **(12L+3T)**

**Unit III**

Independence of two events and n (> 2) events, sequence of independent events, independent classes of events, π-system and λ-system of events, Dynkin's theorem (without proof) independence of r.v.s, Borel zero-one law, Borel - Cantelli Lemma, Kolmogorov zero- one law.

**(12L+3T)**

**Unit IV**

Convergence of a sequence of r.v.s., convergence in probability, almost sure convergence, convergence in quadratic mean and convergence in distribution, and their interrelationships, examples and problems on these concepts.

**(12L+3T)**

**Total (48L+ 12T)**

**ST 8: Limit Theorems in probability (2 credits)**

**Unit I**

Cramer's theorem (Slutsky's theorem) on algebraic properties of convergence in distribution and convergence in probability. Monotone convergence theorem and dominated convergence theorem, Fatou's lemma. Problems and examples on these concepts. **(12L+3T)**

**Unit II**

Laws of large numbers, weak law of large numbers , strong law of large numbers. Khintchin weak law of large numbers, Kolmogorov strong law of large numbers (without proof). ,Continuity theorem for characteristic functions. Lindeberg's CLT (without proof) and its particular cases: Liapounov's theorem, CLT for i.i.d random variables.

**(12L+3T)**

**Total (24L + 6T)**

**Books Recommended:**


1. Athreya K. B. and Lahiri S. (2006). Probability Theory Vol 41, Trim series, (Hindustan Book Agency).
2. Bhat, B. R. (1985). Modern Probability Theory (New Age International)
3. Billingsley, P. (1986). Probability and Measure (John Wiley)
4. Feller, W. (1969). Introduction to Probability and its Applications Vol.II (Wiley Eastern Ltd.)
5. Gnedenko, B. V. (1988). Probability Theory (Mir.Pub.)
6. Gut, Allan (2005), Probability: A Graduate Course. (Springer, New York)
7. Loeve, M. (1978). Probability Theory (Springer Verlag). Fourth edition.


**ST 9 (T): Multivariate Analysis (4 Credits)**

**Unit I**

Exploratory multivariate data analysis, sample mean vector, sample dispersion matrix, correlation matrix, graphical representation, means, variances, covariances, correlations of linear transforms. Introduction to principle component analysis, factor analysis. Canonical correlation coefficients and canonical variables. **(12L + 3T)**

**Unit II**

Cluster Analysis and multidimensional scaling.

Multivariate normal distribution, pdf and mgf, singular and nonsingular normal distributions, distribution of a linear form and a quadratic form of normal variables, marginal and conditional distributions.

**(12L + 3T)**

**Unit III**

MLE's of the parameters of multivariate normal distribution and their sampling distributions, properties of the Wishart Distribution, tests of hypothesis about the mean vector of a multivariate normal distribution, Hotelling's $T^2$-statistic and its distribution, applications of Hotelling's $T^2$-statistic. Goodness of fit of multivariate normal distribution, simultaneous confidence interval for the linear functions of the mean. Tests of significance for multiple and partial correlation coefficients.

**(12L + 3T)**

**Unit IV**

Classification problem. Discriminant analysis, Mahalanobis $D^2$-statistic, methods and applications of MANOVA (without derivation of the distribution of Wilks' lambda).

Likelihood ratio tests, introduction to Non-Gaussian multivariate distributions such as multivariate beta, t, F distributions, Introduction to copula and its applications.

Introduction to directional data analysis.

**(12L + 3T)**

**Total (48L + 12T)**

**Books Recommended :**


1. Anderson, T. W. (1984). Introduction to Multivariate Analysis (John Wiley)
2. Fang ,K., Kotz, S., Ng K. W. (1990). Symmetric Multivariate and Related Distributions (Chapman and Hall)
3. Härdle, W. K. & Simar, L. (2012). Applied Multivariate Statistical Analysis (Springer, New York)
4. Härdle, W. K., Hlávka, Z. (2007). Multivariate Statistics: Exercises and Solutions (Springer, New York)
5. Johnson R.A. & Wichern, D.W. (1988). Applied Multivariate Statistical Analysis (Prentice Hall Inc.)
6. Kotz, S., Balakrishnan N. and Johnson N. L. (2000). Continuous Multivariate Distributions, Volume 1, Models and Applications (John Wiley & Sons)
7. Kshirsagar, A. M. (1983). Multivariate Analysis (Marcel Dekker)
8. Mardia ,K. V. & Jupp, P. E. (2000), Directional Statistics (John Wiley & Sons)
9. Morrison, D.F. (1990). Multivariate Statistical Methods (McGraw Hill Co.)

10. Rao, C. R. (1995). Linear Statistical Inference and its Applications (Wiley Eastern)
11. Timm, N. H. (2002), Applied Multivariate Analysis (Springer, New York)

**ST 9 (P): Multivariate Analysis Practical (2 Credits)**

**Unit I**

1. Graphical representation of multivariate data
2. Principal Component Analysis
3. Factor Analysis
4. Cluster Analysis
5. Canonical Correlations

**Unit II:**

1. Model Sampling from multivariate normal distribution
2. Likelihood ratio tests
3. Applications of Hotelling's $T^2$
4. MANOVA
5. Discriminant Analysis

**Books Recommended:**

Khattree, R. & Naik D. N. (2003), Applied Multivariate Statistics with SAS Software, Second Edition (SAS Institute and Wiley), Chapter 2

**ST 10: Point &Interval Estimation (3 credits)**

**Unit I**

Point estimation, sufficiency, sufficient partition, Neyman Factorization theorem. Minimal Sufficiency, one parameter exponential family, canonical form of exponential family, convexity property, minimal sufficiency in one parameter exponential family, ancillary statistic, Basu's theorem .

**(12L + 3T)**

**Unit II**

Pitman family of distributions, minimal sufficiency in Pitman family, completeness of family, complete statistic, completeness of one parameter exponential family and Pitman family. Unbiased Estimator, estimability of parametric functions, Cramer-Rao inequality, uniformly minimum variance unbiased estimators, Rao-Blackwell Theorem, Lehmann Scheffe theorem,

**(12L + 3T)**

**Unit III**

Multi-parameter exponential family, complete sufficient statistic for multi-parameter exponential family. Confidence sets and intervals, shortest expected length confidence intervals, relation with testing of hypotheses.

**(12L + 3T)**

**Total (36L + 9T)**

**ST 11: Testing of Hypotheses (3 credits)**

**Unit I**

Test function, most powerful test function, Neyman- Pearson lemma for most powerful test functions. Uniformly most powerful tests, UMP tests for simple null against one sided alternative for one parameter exponential class of densities, UMP tests for one sided null against one sided alternative for one parameter exponential class of densities. **(12L + 3T)**

**Unit II**

Non existence of UMP tests for simple null against two sided alternative for one parameter exponential class of densities. Monotone likelihood ratio property, UMP tests for one sided null against one sided alternative for distributions having MLR property, UMP Unbiased tests in exponential family.

**(12L + 3T)**

**Unit III**

Non parametric tests: derivation of the test statistics and its null distribution. Tests of goodness of fit, Kolmogorov-Smirnov one-sample test, Applications of the Kolmogorov-Smirnov one-sample test, Lilliefors's test for normality. Tests based on sample quantiles: Sign test, Wilcoxon signed-rank test. General two-sample problem: Wald-Wolfowitz runs test, Kolmogorov-Smirnov two sample test, Mann-Whitney U test. Linear rank tests for the location problem: Wilcoxon rank-sum test. Linear rank tests for the scale problem: Sukhatme test. Tests of the equality of k Independent samples: Kruskal-Wallis test.

**(12L + 3T)**

**Total (36L + 9T)**

**Books Recommended:**


1. Casella, G. and Berger, R. L. (2002) Statistical Inference. (Duxbury Advanced Series). Second Edition.
2. Dudewicz, E. J. and Mishra, S.N.(1988) Modern Mathematical Statistics. (John Wiley)
3. Gibbons, J.D. and Chakraborty, S. (2003). Nonparametric Statistical Inference. (Marcel Dekker Inc., New York), Fourth edition
4. Kale, B.K. (1999) A First Course on Parametric Inference. (Narosa).
5. Lehmann, E. L. (1986) Testing of Statistical hypothesis (John Wiley )
6. Lehmann, E. L. (1988) Theory of Point Estimation (John Wiley)
7. Lehmann, E.L. and Casella, G. (1998). Theory of Point Estimation. (Springer-Verlag, New York) Second edition
8. Rohatgi, V. K. and Saleh, A.K. Md. E. (2001) Introduction to Probability and Statistics. (John Wiley & Sons)
9. Shao, J. (2003). Mathematical Statistics. (Springer-Verlag, New York) Second edition.
10. Silvey, S. D. (1975) Statistical Inference. (Chapman and Hall)

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**ST 12 (T): Regression Analysis (4 credits)**

**Unit I**

Simple linear regression, assumptions, inference related to regression parameters, standard error of prediction, tests on intercepts and slopes, extrapolation, diagnostic checks and correction: graphical techniques, tests for normality, uncorrelatedness, homoscedasticity, lack-of-fit testing, polynomial regression, transformations on Y or X (Box-Cox, square root, log etc.), method of weighted least squares, inverse regression.

**(12L+3T)**

**Unit II**

Multiple regression: standard Gauss Markov setup, least squares (LS) estimation, variance-covariance of LS estimators, estimation of error variance, regression ananlysis with correlated observations, LS estimation with restriction on parameters. Simultaneous estimation of linear parametric functions. Test of hypotheses for one and more than one linear parametric functions, confidence intervals and regions. Variable selection problems, multicollinearity and ridge regression, LASSO.

**(12L+3T)**

**Unit III**

Logistic Regression: Logit transform. ML estimation. Tests of hypotheses, Wald test, LR test, score test, test for overall regression, multiple logistic regression, forward, backward method, interpretation of parameters, relation with categorical data analysis. Generalized Linear model: link functions such as Poisson, binomial, inverse binomial, inverse Gaussian, gamma. **(12L+3T)**

**Unit IV**

Non Linear Regression (NLS): Linearization transforms, their uses & limitations, examination of non linearity, initial estimates, iterative procedures for NLS, grid search, Newton-Raphson, steepest descent, Marquardt's methods. Introduction to semiparametric regression models, additive regression models. Introduction to nonparametric regression methods.

**(12L+3T)**

**Total (48 L+ 12T)**

**Books Recommended:**


1. Cameron, A. C. and P. K. Trivedi (1998). Regression Analysis of Count Data (Cambridge)
2. Draper, N. R. and Smith, H. (1998). Applied Regression Analysis (John Wiley) Third Edition.
3. Hosmer, D. W. and Lemeshow, S. (1989). Applied Logistic Regression (Wiley).

4. Kleinbaum, D. G. & Klein, M. (2002). Logistic Regression: A Self-Learning Text (Springer).
5. McCullagh, P. and Nelder, J. A. (1989). Generalized Linear Models (Chapman & Hall).
6. Montgomery, D. C., Peck, E. A. and Vining, G. G. (2003). Introduction to Linear Regression Analysis (Wiley).
7. Neter, J., W., and Kutner, M. H. (1985). Applied Linear Statistical Models (Wiley).
8. Ratkowsky, D. A. (1983). Nonlinear Regression Modelling, Marcel Dekker, London.
9. Ruppert, D., Wand, M. P. and Carroll, R. J. (2003) Semiparametric Regression (Cambridge University Press).
10. Seber, G. E. F. and Wild, C. J. (1989). Nonlinear Regression (Wiley).
11. Weisberg, S. (2005). Applied Liner Regression (Wiley).
12. Yan, X. and Su, X. G. (2009). Linear Regression Analysis: Theory & Computing, (World Scientific).

**ST 12 (P): Regression Analysis Practical (2 Credits)**

**Unit I**

1. Simple Linear Regression
2. Multiple Regression
3. Variable Selection Problem
4. Multicollinearity and Ridge Regression

**Unit II**

1. Nonlinear regression
2. Nonparametric regression
3. Logistic regression (binary and multiple)
4. Poisson/Negative binomial regression