NORTH MAHARASHTRA UNIVERSITY
JALGAON

SYLLABUS

FOR

M.Sc. STATISTICS
(Semester I and II)
With specialization in Industrial Statistics

WITH EFFECT FROM ACADEMIC YEAR 2012-2013

NORTH MAHARASHTRA UNIVERSITY, JALGAON
Syllabus for M.Sc. (Statistics)
With specialization in Industrial Statistics

(With effect from Academic Year 2012-2013)

Syllabus Structure

Semester-I

Course Code	Title of the Course	Contact hours/week			Distribution of Marks for Examination						Credits
					Internal		External		Total		
		Th(L)	Pr	Total	Th	Pr	Th	Pr	Th	Pr	
ST-101	Real Analysis	04	--	04	40	--	60	--	100	--	04
ST-102	Linear Algebra	04	--	04	40	--	60	--	100	--	04
ST-103	Sample Surveys and Statistics for National Development	04	--	04	40	--	60	--	100	--	04
ST-104	Distribution Theory	04	--	04	40	--	60	--	100	--	04
ST-105	Computer Programming in C++ and Numerical Methods	04	--	04	40	--	60	--	100	--	04
ST-106	Practicals- I	--	06	06	--	40	--	60	--	100	04

Semester-II

Course Code	Title of the Course	Contact hours / week			Distribution of Marks for Examination						Credits
					Internal		External		Total		
		Th(L)	Pr	Total	Th	Pr	Th	Pr	Th	Pr	
ST-201	Probability Theory	04	--	04	40	--	60	--	100	--	04
ST-202	Stochastic Processes	04	--	04	40	--	60	--	100	--	04
ST-203	Multivariate Analysis	04	--	04	40	--	60	--	100	--	04
ST-204	Parametric Inference	04	--	04	40	--	60	--	100	--	04
ST-205	Linear Models and Regression Analysis	04	--	04	40	--	60	--	100	--	04
ST-206	Practicals-II	--	06	06	--	40	--	60	--	100	04

Th: Theory **Pr: Practicals** **L: Lectures**

Examination Pattern:

There would be continuous internal assessment (CIA) and an end of term examination (ETE) for each course. CIA includes examinations, assignments, viva-voce examinations and presentations.

Number of Internal Tests and Time duration:

Concern Teacher in consultation with Head of the Department may conduct 2 or 3 tests of 40 marks with time duration 2 hours for Internal Examination of all Theory and Practical courses. Head of the Department will declare detailed Time-Table well in advance.

External Examination:

Department will conduct external examinations at the end of each semester. Each course will have examination of 60 marks of duration 3 hours. Head of the Department will declare detailed Time-Table for external examinations well in advance.

Standard of Passing:

To pass any course, the candidate has to secure at least 40% marks in the internal as well as in the external examinations. The student failed in Internal or External or in both examinations shall have to appear for subsequent Internal or External or both Examinations respectively for that course. The student having the backlog of any course(s) from first year of M.Sc. can be admitted to second year of M.Sc.

Award of class/Grade: As per the University's common rules of CGPA system.

Declaration of results: By COE, N.M.U., Jalgaon.

Verification or revaluation: As per the University's rules.

General Instructions to Teachers and Paper Setters/ Examiners

1. Each Theory Course requires 60 lectures each of one hour.
2. Each Practical Course requires 90 laboratory periods each of one hour.
3. Numbers of Lectures/periods to be devoted for each topic and minimum number of marks to be allotted out of 60 for main topics are mentioned in parentheses in the detailed syllabi.
4. Teacher should follow syllabus as well as time schedule given in the syllabus for all topics. Variation up to 4 to 5 hours (more or less) may be acceptable.
5. Each external examination theory question paper should contain 5 questions each of 12 marks (all questions will be compulsory with internal choices).
6. Each external practical examination question paper should contain sections as made in the syllabus. Paper setter may consider sub parts such as ((a), (b), (c)…) in each section for internal choices.
7. Question paper should generally be uniformly distributed over the syllabus.

ST-101: REAL ANALYSIS

- **The Real Number System: (8 Marks)**

  - Introduction, The field axioms, the order axioms, Geometric representation of real numbers, Intervals, Integers, The unique factorization theorem for integers. (2L)
  - Rational numbers, Irrational numbers, Upper bounds, Lower bounds, Least upper bound (supremum), Greatest lower bound (infimum) of the sets of real numbers. (2L)
  - The completeness axiom, some properties of the supremum and infimum, Archimedean property of the real number system. (2L)
  - Rational numbers with finite decimal representation, Finite decimal approximations to real numbers, Infinite decimal representation of real numbers. (1L)
  - Absolute values and the triangle inequality, The Cauchy-Schwarz inequality, Plus and minus infinity and the extended real number system R^*. (1L)

- **Basic Notions of Set Theory: (6 Marks)**

  - Ordered pairs, Cartesian product of two sets, Relations and functions. Further terminology concerning functions, One-to-one functions and inverses, Composite functions. (2L)
  - Similar (equinumerous) sets, Finite and infinite sets, Countable and uncountable sets, Uncountability of real number system. (2L)
  - Set algebra, countable collections of countable sets and related results. (2L)

- **Elements of Point Set Topology: (5 Marks)**

  - Introduction to n-dimensional Euclidean space, Open and closed intervals (rectangles), Open and closed sets on the real line, limit points of a set, Compact set. (2L)
  - The Bolzano-Weierstrass theorem, Heine-Borel theorem for real line R (without proof). (1L)

- **Sequences and Series of Real Numbers: (15 Marks)**

  - Introduction and examples of sequences of real number. (1L)
  - Convergence of sequences, limit of a sequence, limit superior and limit inferior of a real-valued sequences, Monotone sequences of real numbers. (2L)
  - Cauchy sequences and related results. (2L)
  - Infinite series, Alternating series. (1L)
  - Convergence of Series, Absolute and conditional convergence. (1L)
  - Test for convergence of series with positive terms (Comparison test and limit comparison test). (1L)
  - The geometric series. (1L)
  - The integral test. (1L)
  - The big O(h) and little o(h) notation. (1L)
  - The Ratio test and Root test, Abel's test. (2L)

- **Limit and Continuity: (6 Marks)**
  - Limits of functions. (1L)
  - Continuous functions. (1L)
  - Uniform continuity. (1L)
  - Discontinuities. (1L)
  - Continuity and compactness. (2L)
  - Monotone function and discontinuities. (1L)

- **Sequences of Functions: (6 Marks)**

  - Introduction and examples of sequences of real-valued functions. (1L)
  - Pointwise convergence of sequences of functions. (1L)
  - Definition of uniform convergence, Uniform convergence and continuity. (2L)
  - Power series and radius of convergence. (1L)

- **Differentiation and functions of several variables. (6 Marks)**

  - The Derivative of a Real Function. (1L)
  - Maxima-minima of function, Mean value theorems. (2L)
  - The Continuity and Derivatives. (1L)
  - Derivatives of higher order, Taylor's theorem (without proof). (1L)
  - Functions of several variables, constrained maxima-minima functions. (2L)

- **Integrals: (8 Marks)**

  - Riemann and Riemann- Stieltjes integrals, integration by parts, mean value theorem. (3L)
  - Multiple integrals and their evaluation by repeated integration. (2L)
  - Change of variables in multiple integration. (2L)
  - Improper Riemann – Stieltjes integrals: Improper integrals of first and second kind for one variable, uniform convergence of improper integrals. (2L)
  - Differentiation under the sign of integral Leibnitz rule. (2L)

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Apostol, T. M. (1985). Mathematical Analysis, (Narosa, Indian Ed.).

Courant, R. and John, F. (1965). Introduction to Calculus and Analysis, (Wiley).

Miller, K. S. (1957). Advanced Real Calculus, (Harper, New York).

Rudin, Walter (1976). Principles of Mathematical Analysis, (McGraw Hill).

Malik, S. C. (2005). Principles of Real Analysis, (New Age Inter-national (P) Ltd.).

Bartle, R. G. (1976). Elements of Real Analysis, (Wiley).

ST-102: LINEAR ALGEBRA

- **Preliminaries: (2 Marks)**
  - Binary operations, Groups, Polynomials. (2L)

- **Vector Spaces (VS) : (12 Marks)**
  - Definition of VS, Subspaces, Linear span of set, examples of VS over real and complex fields. (3L)
  - Linear span of a set, Span of a set as a smallest subspace containing the set, Generating set of VS, Results on span of a set. (2L)
  - Intersection and union of sub spaces, Completion theorem. (2L)
  - Linear dependence and linear independence of set of vectors, Necessary and sufficient condition for linear dependence of set of vectors. (2L)
  - Steinitz exchange theorem, Maximal linearly independent set, minimal generating sets. (2L)
  - Basis of VS, Dimension, Extension of linearly independent set to a basis (algorithm and theorem), relation between dimensions of subspaces; one of which is subset of other. (4L)
  - Sum of 2 sets, modular law. (1L)

- **Algebra of Matrices: (12 Marks)**
  - Linear transformations and matrices, Addition, Scalar multiple and composition of linear transformation, The corresponding operations on matrices, Elementary properties of matrix operations, Upper and lower triangular matrices, Trace of a matrix and related results. (3L)
  - Row and column spaces, Rank of a matrix, Left inverse, Right inverse and inverse of a matrix, properties of inverse, Upper bound for rank of product of matrices, Rank cancellation laws. (2L)
  - Rank factorization theorem, properties of idempotent matrix (1L)
  - Nullity of matrix, null space of a matrix, relation of rank of null space of a matrix with rank of a matrix. (2L)
  - Lower bound for rank of product of 2 matrices, Rank of sum of matrices. (1L)
  - Partitioned matrix, Elementary matrix, Determinant of a matrix, Its elementary properties, Determinant and inverse of partitioned matrix, Kronecker product. (3L)

- **Linear Equations of Systems of Equations: (8 Marks)**
  - Consistent and inconsistent system of equations, Homogeneous systems and existence of nontrivial solution for it, General linear systems, Solution of systems of equations. (3L)
  - Generalized inverse of a matrix and its properties, Moore-Penrose generalized inverse, Solution of systems of equations. (3L)

- **Inner Product and Orthogonality: (10 Marks)**

  - VS with inner product, Normed vector spaces, Cauchy-Schawrz inequality, Orthogonality and linear independence. (2L)
  - Orthonormal basis, Expression of any vector in VS as a linear combination of elements of orthonomal basis. (2L)
  - Gram-Schmidt orthogonalization process, Extension of any orthogonal set to orthonomal basis of VS, Examples. (2L)
  - Orthogonal and unitary matrices and their properties. (2L)

- **Eigen Values: (8 Marks)**

  - Characteristic polynomial and characteristic equation of a matrix, Characteristic roots, their properties. (2L)
  - Eigen values and eigen vectors, Eigenspaces, Geometric and algebraic multiplicity of an eigen value, Relation between the 2 multiplicities, Simple and regular eigen values, Properties of eigen values. (3L)
  - Cayley-Homilton theorem and minimal polynomial, Singular values and singular vectors. (2L)
  - Spectral decomposition of real symmetric matrix, singular value decomposition, Jordan decomposition. (2L)

- **Quadratic Forms (QF): (8 Marks)**

  - Real QF, Classification, Rank and signature, reduction of any QF to diagonal form. (2L)
  - Definiteness of a matrix, equivalence of nonnegative definite matrix and variance-covariance matrix, Simultaneous reduction of two QF. (3L)
  - Extrema of QF, Maxima and Minima of ratio of two QF. (2L)

REFERENCES

Graybill, F.A.(1983). Matrices with Applications in Statistics (2nd Ed. Wadsworth)

Rao, A.R. and Bhimasankaram, P. (2000). Linear Algebra. (Hindustan Book Agency).

Rao, C.R. (2002). Linear Statistical Inference and its Applications. (2nd ed. John Wiley and Sons Inc.).

Searle, S. R. (1982). Matrix Algebra Useful for Statistics. (John Wiley and Sons Inc.).

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Bellman, R.(1970). Introduction to Matrix Analysis, (2nd ed.Tata McGraw Hill).

Biswas, S.(1984). Topics in Algebra of Matrices, (Academic Publictions).

Hadley, G.(1987). Linear Algebra, (Narosa Publishing House).

Halmos, P.R.(1958). Finite-dimensional Vector Spaces, (2nd ed. D.Van Nostrand Company, Inc.).

Hoffman, K. and Kunze, R. (1971). Linear Algebra, (2nd Ed.Prentice Hall, Inc.)

Rao, C.R. and Mitra, S.K. (1971). Generlized Inverse of Matrices and its Applications, (John Wiley and Sons Inc.).

ST-103: SAMPLE SURVEYS AND STATISTICS FOR NATIONAL DEVELOPMENT

- ## Sample Surveys:

  - **Preliminaries: (6 Marks)**

    - Objectives of sample survey, planning for sample survey. (1L)
    - Basic issue related to estimation [biased and unbiased estimator, mean square error (MSE)] and confidence interval (2L)
    - Concept of sampling distribution of statistic (2L)
    - Sampling and non-sampling errors (1L)

  - **Review of basic methods of sample selection from finite population. (10 Marks)**

    - Simple random sampling with replacement, Simple random sampling without replacement, Systematic sampling and related results on estimation of population total, mean and proportion. (5L)
    - Stratified sampling: Formation of strata and number of strata, Allocation problems and estimation problems. (5L)

  - **Unequal Probability Sampling Designs: (8 Marks)**

    - Inclusion probabilities, Horwitz-Thompson estimator and its properties. (3L)
    - PPSWR, PPSWOR methods (including Lahiri's scheme) and related estimators of a finite population mean (Heansen-Horwitz and Desraj estimators for a general sample size and Murthy's estimator for a sample of size 2). (5L)
    - Midzuno sampling design, πps design. (3L)

  - Use of supplementary information for estimation, Ratio and Regression estimators based on SRSWOR method of sampling, Their properties and MSEs. (5 Marks,5L)
  - The Jackknife technique. (2 Marks,2L)
  - Cluster sampling, Estimator of population mean and its properties. (4 Marks,3L)
  - Two-stage sampling with equal number of second stage units. (2 Marks,2L)
  - Double sampling and its uses in ratio and regression estimation. (3 Marks,3L)
  - Randomized response technique, Warner's model; related and unrelated questionnaire methods. (4 Marks, 3L)

- ## Statistics for National Development:

  - **Economic Development: (6 Marks)**
    - Growth in per capita income and distributive justice. (1L)
    - Indices of development. (1L)
    - Human Development indexes. (1L)
    - Estimation of national income-product approach, income approach and expenditure approach. (2L)

- Population growth in developing and developed countries, Population projection using Leslie matrix, Labour force projection. (2 Marks, 2L)
- Measuring inequality in incomes, Lorenz curve, Gini coefficient, Theil's measure. (2 Marks, 2L)

- **Poverty measurement: (6 Marks)**
  - Different issues related to poverty. (2L)
  - Measures of incidence and intensity. (2L)
  - Combined measures e.g. Indices due to Kakwani, Sen etc. (2L)

REFERENCES

Sampling Methods:

Cochran, W.G. (1984). Sampling Techniques, (Wiley).
Des Raj and Chandok (1999). Sample Survey Theory, (Narosa).
Sukhatme, P.V, Sukhatme, B.V and Ashok C. (1984). Sampling Theory of Surveys with Applications, (Iowa State University Press & IARS).
Mukhopadhay P. (2002). Theory and Method of Sample Survey, (Chapman and Hall)

Statistics for National Development:

CSO. National Accounts Statistics- Sources and Health.
Sen, A. (1997). Poverty and Inequality.
Datt R., Sundharam, K. P. M. (Revised edition). Indian Economy, (Sultan Chand & company Ltd.)

ST-104: DISTRIBUTION THEORY

- **Brief review of basic distribution theory: (5 Marks)**
  - Random experiment and its sample space, events. (1L)
  - Probability axioms. (1L)
  - Random variables, Discrete random variables, Continuous random variables. (1L)
  - P.d.f., p.m.f., c.d.f. of random variables. (1L)
  - M.g.f., p.g.f., c.g.f., characteristic function of random variables. (1L)
  - Moments: raw moments, Central moments, Factorial moments. (1L)
- **Standard discrete and continuous distributions: (8 Marks)**
  - Bernoulli, Binomial, Geometric, Negative Binomial, Poisson, Hypergeometric distributions. (2L)
  - Exponential, Normal, Gamma, Beta, Uniform, Chi-square, Lognormal, Weibull, Cauchy distributions. (2L)
  - M.g.f, p.g.f., c.g.f., characteristic function, Moments of above distributions. (2L)
  - Properties of above distributions. (2L)
- **Joint, Marginal and Conditional distributions: (10 Marks)**
  - Concept of random vectors, Joint, Marginal and conditional distributions Variance-covariance matrix. (1L)
  - Joint p.m.f. of discrete random variables, Joint p.d.f. of continuous random variables. (1L)
  - Marginal and conditional density using joint density. (1L)
  - Conditional expectation and variance. (1L)
  - Independence of random variables. (1L)
  - Bivariate normal distribution; Joint p.d.f. Marginal p.d.f.s, Conditional p.d.f., Joint m.g.f., Some properties. (2L)
  - Bivariate exponential distribution: joint p.d.f., Marginal p.d.f.s, properties. (1L)
  - Multivariate normal distribution: joint p.d.f., Marginal p.d.f., Conditional p.d.f., Joint m.g.f. (2L)
  - Multinomial distribution: joint p.m.f., Marginal p.m.f., Conditional p.m.f., Joint m.g.f. (2L)
- **Functions of random variables and their distributions: (10 Marks)**
  - Function of random variables. (1L)
  - Joint density of functions of random variables using jacobian of transformation. (3L)
  - Convolution of random variables. (1L)
- **Compound, Truncated and Mixture Distributions: (3 Marks)**
  - Concept, applications, examples and problems. (3L)

- **Regression: (3 Marks)**
  - Linear and multiple regression, Regression Function, Best linear regression function. (3L)
- **Correlation: (3 Marks)**
  - Multiple and Partial Correlation. (2L)
- **Sampling Distributions: (6 Marks)**
  - Introduction, Sampling distribution of statistics from univariate normal random samples. (2L)
  - Non-central Chi-square, t and F- distributions and their properties. (5L)
- **Quadratic forms under Normality: (6 Marks)**
  - Distribution of linear and quadratic forms in i.i.d. Standard normal variables (Technique based on m.g.f.). (2L)
  - Independence of two linear forms, Independence of two quadratic forms and independence of linear form and quadratic form. (2L)
  - Fisher Cochran's theorem. (2L)
- **Order Statistics: (6 Marks)**
  - Distribution of r^{th} order statistics, Joint distribution of several order statistics and their functions. (4L)
  - Distribution of function of order statistics. (2L)
  - Extreme values and their asymptotic distributions (statement only) with applications. (2L)

REFERENCES

Rohatgi V.K. and Ehsanes Saleh A. K. MD. (2003). An Introduction to Probability Theory and Mathematical Statistics, (Wiley Eastern, 2nd Ed.).

Hogg, R.V. and Craig, A.T. (1978). Introduction to Mathematical Statistics, (5th Ed. Pearsons Education).

Hogg, R.V. and Tanis E.(2002) An. Probability and Statistical Inference (6th Ed. Pearsons Education).

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Dudewicz, E. J. and Mishra, S. N. (1988). Modern Mathematical Statistics, (Wiley & Sons).

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Cramer H. (1946). Mathematical Methods of Statistics, (Princeton).

ST-105: COMPUTER PROGRAMMING IN C++ AND NUMERICAL METHODS

Computer Programming in C++ (40 Marks)

- Principles of Object-Oriented Programming. (3L)
- Beginning with C++. (3L)
- Tokens, Expressions and Control Structures. (6L)
- Functions in C++. (3L)
- Classes and Objects. (5L)
- Constructors and Destructors. (5L)
- Operator Overloading and Type Conversions. (5L)
- Inheritance: Extending Classes. (3L)
- Pointers, Virtual Functions and Polymorphism. (3L)
- Managing Console I/O Operations. (3L)
- Working with Files (including linking to databases). (4L)

Numerical Methods: (20 Marks)

- **Errors in Numerical Calculations**
  Introduction, Errors and their Analysis. A general error formula, error in series approximation. (3L)
- **Iterative methods**
  Introduction, the method of successive bisection, Newton-Raphson method. (3L)
- Interpolation (2L)
- Solution of Simultaneous Algebraic Equations
  Introduction, Direct method, Matrix Inversion Method, The Gauss elimination method, Pivoting, The Gauss-Seidel iterative method, The Eigen value Problem. (3L)

- Numerical Integration
  Introduction, Simpson's 1/3 rule, Trapezoidal Rule, Quadrature Rule, Simpson's 3/8 Rule, Errors in integration formulae, Monte Carlo integration. (6L)

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K. R. Venugopal, Rajkumar, J.Ravishankar. Mastering C++.

V. Rajaraman (1993). Computer Oriented Numerical Methods, (3rd Ed. Prentice-Hall)

W. H. Press, S. A. Teukolsky, W.T. Vellering and B.P.Flannery (1993). Numerical Recipes in C, (2nd Ed. Cambridge University Press).

R.A. Thisted (1988). Elements of Statistical Computing, (Chapman and Hall).

Ross, S. (2005). Introduction to Probability Models, (6th Ed. Academic Press).

ST-106: PRACTICALS-I

A. Introduction to WIDOWS-XP and different Statistical Software Packages (4 Marks) (10 Hrs.: First 2 weeks)

(Introduction can be done through following simple practical)

1. Classification, tabulation and frequency tables.
2. Bar graphs, histogram.
3. Stem-and- Leaf plots, Box plots.
4. Summary statistics.
5. Two-way tables and plots.
6. Scatter diagram correlation coefficient.

B. Practicals based on Linear Algebra. (Using software packages) (10 Hours, 8 Marks)

1. Checking linear dependence/independence of set of vectors using system of linear equations. (1L)
2. Getting vectors in row/column space and null space of the given matrix. (1L)
3. Computation of inverse of a given matrix.
   - Natural inverse.
   - G-inverse, left and right inverse
   - MP-inverse (1L)
4. Computing higher order powers of a given matrix using spectral decomposition. (1L)
5. To obtain rank factorization of given non-null matrix. (1L)
6. Gram-Schmidt orthonormalization, forming an orthogonal matrix of specified order using Gram-Schmidt orthogonalization, forming an orthogonal matrix containing a specified vector as a row/column of the matrix. (2L)
7. Checking and demonstrating the definiteness of the given matrix, getting vectors from eigen-space, algebraic and geometric multiplicity of an eigen value etc. (1L)
8. Demonstration of occurrence of maxima and minima of
   - Quadratic forms over normed vectors.
   - Ratio of two quadratic forms over normed vectors. (1L)
9. Verification of Cayley-Hamilton theorem (1L)

C. Practicals based on the Sampling Theory and Statistics for National Development. (Using software packages) (26 Hours, 20 Marks)

1. Model Sampling and Estimation (4L)
   - Drawing simple random samples from a given finite population using SRSWR and SRSWOR.
   - Estimating the population total, mean and proportion using the sample drawn.
   - Estimating the variance of the estimator obtained above using the sample drawn.
   - Confidence interval for population total, mean and proportion.
   - Comparison of two estimators.
   - Minimum sample size requirement.

2. Stratified Random Sampling (4L)
   - Various kinds of allocation and estimation of population total and mean with S.E.
   - Post stratification.
3. Using Auxiliary Information (4L)
   - Ratio method of estimation
   - Regression method of estimation.
4. H-T estimator and PPS, π PS designs (2L)
5. Double Sampling. (2L)
6. Systematic Sampling (2L)
7. Cluster Sampling (2L)
8. Two stage sampling (2L)
9. Randomized Response Technique (1L)
10. Practical based on Estimation of national income, Income inequality, Poverty measurement. (3L)

D. Practical based on Distribution Theory. (Using software packages) (4 Marks)

1. Generating random samples from discrete, continuous and mixture distributions (2L)
2. Fitting of standard distributions and tests for goodness of fit. (2L)

E. Practicals based on Computer Programming C++ and Numerical Methods. (40 Hrs, 24 Marks)

1. Writing programs to calculate different summary statistics (mean median, mode, variance, standard deviation, order statistics, range and quantiles) based on the given *n* observations. (3L)
2. Programs to compute the c.d.f.'s of standard probability distributions. (Binomial, Poisson, Geometric, Hyper Geometric, Negative Binomial) (9L)
3. Drawing random samples from standard distributions (Binomial, Poisson, Geometric, Exponential, Normal, Gamma, Beta, Discrete, Mixture) (6L)
4. Drawing a random sample of size *n* using SRSWR and SRSWOR. (2L)
5. Write a program to define a specified class. Use member function, friend function and overload the specified operators to perform the following tasks. (9L)
   - To create an object of type class.
   - To modify the value of the element of object of a class.
   - To perform unary/binary operations on object.
6. Programs based on the numerical methods. (7L)
   - Bisection method, Newton-Raphson Method
   - Numerical Integration by Simpson's rules
7. Program to compute c.d.f. of normal distribution. (2L)
8. Computing expectations of complicated functions. (2L)

F. Assignment Problem to be solved by students.

1. Preparing frequency distribution of given data.
2. Calculation of p-value for standard Normal distribution (for given Z value)
3. Calculation of regression and correlation coefficients.
4. Sketching p.d.f of the given distribution for various parameters.(Using software)

ST-201: PROBABILITY THEORY

- **Sets and Classes of Events: (6 Marks)**
  - Random experiment, Sample space and events. (1L)
  - Algebra of sets. (1L)
  - Sequence of sets, limit supremum and limit infimum of sequence of sets. (2L)
  - Classes of sets, Sigma-fields (σ-fields), Minimal fields, Minimal σ-field, Partition. (3L)
  - Borel fields in R^1 and R^k , Monotone field. (2L)

- **Random Variables: (6 Marks)**
  - Point function and set function, Inverse function. (2L)
  - Measurable function, Borel function, induced σ-field, Function of a function, Borel function of measurable function. (2L)
  - Real and vector-valued random variable. (2L)
  - σ-field induced by a sequence of random variables. (1L)
  - Limits of Random variable. (2L)

- **Measure and Probability Measure: (6 Marks)**
  - Measure (Definition and simple properties). (1L)
  - Probability measure, Properties of a measure. (1L)
  - Probability space (finite, countable) Continuity of a probability measure. (1L)
  - Extension of probability measure, Caratheodory Extension theorem (without proof). (1L)
  - Probability space induced by r.v. X , Distribution of Borel functions of r.v. (1L)
  - Other measures: Generalized Probability measure, Conditional Probability measure, Counting measure, Lebesgue measure. (2L)

- **Distribution Functions: (6 Marks)**
  - Distribution functions of a r.v. and its properties. (1L)
  - Jordan decomposition theorem, Mixture of distribution functions. (2L)
  - Distribution functions of vector valued r.v.s. (1L)
  - Empirical distribution functions. (1L)

- **Expectation and Moments: (8 Marks)**
  - Integration of measurable function with respect to a measure. (1L)
  - Expectation of a r.v. (Definition for simple, Nonnegative and arbitrary r.v.), Properties of expectation, Expectation of Complex r.v. (3L)
  - Moments, Moment generating function. (1L)
  - Moment inequalities: C_r-inequality, Holder inequality, Schwarz's inequality, Minkowski's inequality, Jensen's inequality, Liapounov's inequality, Basic inequality, Markov inequality, Chebyshev's inequality. (3L)

- **Convergence of Sequence of Random variables: (8 Marks)**

    - Convergence in distribution, Convergence in probability, Almost sure convergence and convergence in quadratic mean and their inter-relations. (5L)
    - Monotone convergence theorem, Fatou's Lemma, Dominated convergence theorem. (3L)

- **Characteristic function: (4 Marks)**

    - Definition and simple properties, Some inequalities. (2L)
    - Uniqueness theorem (statement only), Levy's continuity thereon (Statement only). (1L)

- **Independence: (5 Marks)**

    Independence of two events, Independence of n>2 events, sequence of independent events, independent classes of events, independence of r.v.s, Borel zero-one law. (4L)

- **Law of large numbers: (5 Marks)**

    - Weak laws of large numbers (WLLN), Khintchine's WLLN, Kolmogorov's strong law of large number (Statement only) and their applications. (4L)

- **Central limit theorem (CLT): (6 Marks)**

    - CLT for a sequence of independent r.v.s. under Lindeberg's condition, CLT for i.i.d. r.v.s. and its applications. (3L)

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ST-202: STOCHASTIC PROCESSES

- **Introduction: Stochastic Processes, Markov chains (14 Marks)**

  - Review of conditional probability and Expectation with problems. (2L)
  - Introduction to Stochastic Processes, Classification of Stochastic Processes according to state space and time domain. (1L)
  - Finite and countable state space Markov chains (Definitions and examples). (2L)
  - Chapman-Kolmogorov equations, Calculation of n-step transition probability and its limit. (2L)
  - Stationary distribution of Markov chains. (2L)
  - Classification of states, Period of the state, Transient and recurrent Markov chain and related results. (4L)
  - Random walk and gambler's ruin problem. (2L)
  - First passage time and other problems with applications. (2L)
  - Applications of Markov Chains in Social, Biological and Physical Sciences. (1L)

- **Branching Process: (6 Marks)**

  - Golton-Watson branching process. (2L)
  - Probability of ultimate extinction, Distribution of population size. (2L)
  - Applications. (1L)

- **Discrete state space continuous time Markov Chain. (12 Marks)**

  - Definition and examples. (1L)
  - Markov Pure jumps processes. (2L)
  - Kolmogorov's differential equations. (2L)
  - Poisson process (Definitions, properties and applications). (3L)
  - Birth and death processes, Machine repairmen problem. (2L)
  - Wiener process as a limit of random walk. (2L)

- **Simple Queuing Systems: (6 Marks)**

  - $M|M|1,\ M|M|s,\ M|M|\infty$ queuing systems and their applications. (2L)
  - Stationary solution for $M|M|1,\ M|M|s,\ M|M|\infty.$ using birth and death process approach. (2L)

- **Renewal Theory: (10 Marks)**

  - Renewal process (Definition and examples) (2L)
  - Elementary renewal theorem and its applications (2L)
  - Statement and uses of key renewal theorem (1L)
  - Renewal reward process, Regenerative Process, Semi-Markov process. (2L)
  - Age of renewal process and residual life in renewal processes and their distributions. (2L)

- **MCMC Algorithm:(2 Marks)** (2L)
- **Stationary Process: (2 Marks)**
  - Weakly Stationary and strongly stationary processes. (2L)

- **Inference in Markov chains: (8 Marks)**
- Estimation of transition probabilities, estimation of functions of transition probabilities in Markov chains, Testing of order of a Markov chains, Parametric models and their goodness of fit. (8L)

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Karlin, S.and Taylor, H.M. (1975). A First Course in Stochastic Processes, (Vol.1, Academic Press).

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Ross, S. (2005). Introduction to Probability Models, (6th Ed. Academic Press).

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ST-203: MULTIVARIATE ANALYSIS

- **Introduction to Bivariate Distributions: (4 Marks)**
  - Bivariate normal, Bivariate Poisson, Bivariate Exponential, Bivariate binomial, Bivariate negative binomial. (3L)

- **Multivariate Normal Distribution(MVND): (16 Marks)**
  - Singular and nonsingular MVND, Mean vector and variance covariance matrix. (3L)
  - Characteristic function of MVND. (1L)
  - Additivity property of MVND. (1L)
  - Distribution of linear forms of a vector having MVND, Marginal distributions, Conditional distributions (2L)
  - Necessary and sufficient condition for independence of $\underline{X}^{(1)}$ and $\underline{X}^{(2)}$ (two components of $\underline{X}$). (2L)
  - Central and noncentral χ^2 distribution, their characteristic function, χ distribution. (2L)
  - Distribution of quadratic forms in MVN random vector. (2L)
  - Necessary and sufficient condition for a quadratic form to have χ^2 distribution (1L)
  - Condition for independence of two quadratic forms and its applications, Condition for independence of linear form and quadratic form and its applications. (1L)
  - Random sampling from MVND, Unbiased and maximum likelihood estimators of parameters of MVND, their sampling distributions, independence. (3L)
  - Sample correlation coefficients, their maximum likelihood estimators (mle), Correlation matrix and its mle. (1L)

- **Wishart distribution: (10 Marks)**
  - Wishart matrix, Derivation of Wishart distribution in canonical case and in general case, Bartelett Decomposition theorem. (3L)
  - Characteristic function of Wishart distribution, Additive property of Wishart distribution, Moments of Wishart distribution. (3L)
  - Properties of Wishart distribution. (4L)
  - Necessary and sufficient condition for XAX' to have Wishart distribution and its application. (2L)

- **Hotelling's T^2 and its applications: (10 Marks)**
  - Hotelling's T^2 statistic as a generalization of square of Student's statistic. (1L)
  - Derivation of Hotelling's T^2 statistic from Likelihood Ratio Test, Application of union-intersection principle to obtain Hotelling's T^2 statistic, Invariance of T^2 statistic under scale transformation. (2L)
  - Distance between two populations, Mahalnobis D^2 statistic and its relation with Hotelling's T^2 statistic. (1L)
  - Application of Hotelling's T^2 **:**
    Test of equality of mean vector for one or more multivariate normal population, Test of equality of components of a mean vector of MVND, Two sample problem. (2L)

- Rao's U-statistic and its distribution. (1L)

- **Correlation and regression: (4 Marks)**

  - Sample correlation coefficient, its null and non-null distribution, (1L)
  - Regression of X_1 on X_2, …X_p, properties of residual, multiple correlation coefficient(MCC), m.l.e. of MCC, Null distribution of sample MCC. (2L)
  - Regression of X_1 and X_2 on X_3, …X_p, residuals, partial correlation coefficient(PCC), sampling distribution of PCC. (1L)

- **Discriminant Analysis: (4 Marks)**

  - Cluster Analysis and classification problem. (2L)
  - Classification and discrimination procedure for discrimination between two multivariate normal populations, sample discriminant function, Probabilities of misclassification and their estimation, Optimum error rate, Test associated with discriminant function. (4L)

- **Principal Components: (4 Marks)**

  - Introduction and need, population principal components, Finding i^{th} principal component, correlation of i^{th} principal component with k^{th} element of vector $\underline{X}$, principal component when $\sum$ has special structure, Sample principal components. (3L)

- **Canonical Correlation: (4 Marks)**

  - Concept of canonical correlation as generalization of multiple correlation, Geometrical interpretation and its use, Definition of canonical correlation and canonical variables, Existence of canonical variables, Canonical correlation as a maximum root of characteristic equation of a matrix, Sample canonical correlation and canonical variables. (3L)

- **Multivariate Analysis of Variance (MANOVA): (4 Marks)**

  - MANOVA for one way and two ways classified data, Wilk's Λ criteria. (3L)

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ST-204: PARAMETRIC INFERENCE

- **Introduction: (4 Marks)**

  - Introduction of Parametric models, Point estimation, Tests of hypotheses and Interval estimation. (1L)
  - Joint distribution of a sample and sampling distribution of a Statistic. (2L)
  - Likelihood function; examples from standard discrete and continuous models (such as Bernoulli, Poisson, Negative Binomial, Normal, Exponential, Gamma, Pareto etc.) Plotting likelihood functions for these models up to two parameters. (2L)

- **Sufficiency: (10 Marks)**

  - Information in data about the parameters and variation in likelihood function, concept of no information. (1L)
  - Sufficiency, Fisher's concept of sufficiency, Sufficient Statistic, Neyman Factorizability criterion, Likelihood equivalence, Minimal sufficient Statistic. (4L)
  - Invariance property of sufficiency under one-one transformation of sample space. (1L)
  - Exponential families and Pitman families. (3L)
  - Fisher information for one and several parameters models. (2L)

- **Methods of Estimation: (8 Marks)**

  - Maximum Likelihood method. (3L)
  - Methods of moments and percentiles. (2L)
  - Unbiased Estimation. (1L)

- **Minimum Variance Unbiased Estimation: (12 Marks)**

  - UMVUE, Rao-Blackwell Theorem. (2L)
  - Completeness property of family of distributions. (3L)
  - Lehmann-Scheffe-Rao-Blackwell Theorem and its applications. (2L)
  - Necessary and sufficient condition for UMVUE. (1L)
  - Cramer-Rao lower bound approach. (2L)

- **Tests of Hypotheses: (15 Marks)**

  - Concepts of critical regions, Test functions. (1L)
  - Two kinds of errors, Size function, Power function, Level of the test. (2L)
  - Introduction of null and alternative hypotheses with examples. (1L)
  - Most powerful (MP) and Uniformly Most Powerful (UMP) test in the class of size α tests. (1L)
  - Neyman-Pearson Lemma, MP test for simple null against simple alternative hypothesis. (3L)

- UMP tests for simple null hypothesis against one-sided alternatives and for one-sided null against one-sided alternatives in one parameter exponential family. (3L)
- Extensions of these results of Pitman family when only upper or lower end depends on the parameter. (2L)
- MLR property and extension of the above results to the distributions with MLR property. (2L)
- Non-existence of UMP test for simple null against two sided alternatives in one parameter exponential family. (2L)

- **Interval Estimation: (5 Marks)**

  - Confidence level, construction of confidence intervals using pivots, Shortest expected length confidence interval. (3L)
  - Uniformly most accurate one-sided confidence interval and its relation to UMP test for one-sided null against one-sided alternative hypotheses. (2L)

- **Bayesian Estimation: (6 Marks)**

  - Prior distribution, loss function, principle of minimum expected posterior loss, quadratic and other common loss functions, conjugate prior distributions, common examples. (6L)

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ST-205: LINEAR MODELS AND REGRESSION ANALYSIS

- **General Linear Model: (15 Marks)**

  - Gauss-Markov set up, Least square estimation, Normal equations, Consistency of system of normal equations and their solution. (3L)
  - Estimability of linear parametric function, necessary and sufficient condition for estimability, Best Linear Unbiased Estimator (BLUE). (2L)
  - Gauss-Markov theorem, Variances and covariances of BLUE's. (2L)
  - Estimation space, Error space, their ranks, Orthogonality of estimation space and error space. (2L)
  - Simultaneous estimates of linear parametric function, Estimation of error variance, Estimation with correlated observations. (3L)
  - Least square estimates with restriction on parameters, Method of generalized least squares. (3L)

- **Interval Estimation and Test of Hypothesis: (15 Marks)**

  - Under the normality assumption, Distribution of error sum of squares, Regression sum of squares and distribution of BLUE's, their independence. (2L)
  - Distribution of conditional error sum of squares, Distribution of sum of squares due to null hypothesis. (3L)
  - Test of hypothesis for one or more than one estimable linear parametric function, Test of hypothesis of equality of all estimable functions to zero, Testing of sub hypothesis for full rank model, Power of F-test. (3L)
  - Simultaneous confidence interval for n linearly independent estimable parametric functions. (2L)
  - One way and two way classified data, multiple comparison tests due to Tukey-Scheffe. (4L)

- **Regression Analysis: (30 Marks)**

  - Simple linear regression in Gauss-Markov set up. (2L)
  - Multiple regression model, Estimation of regression coefficients, Regression analysis of variance, Fitted values and residuals. (3L)
  - Polynomial regression, Orthogonal polynomials, Response analysis using orthogonal polynomials. (4L)
  - Residuals and their plots as tests for departure from assumptions such as fitness of the model, Normality, Homogeneity of variances and detection of outliers. (4L)
  - Remedial measures and validation, Multi-collinearity, Ridge regression, Robust regression principal component regression subset selection of explanatory variables, Mallows Cp statistic. (7L)
  - Introduction to non-linear regression models, Least square estimation in non-linear regression, Model building and diagnostics. (4L)
  - Logistic Regression: Logit transform, ML estimation, Test of hypotheses, Wald test, LR test, score test. (7L)

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Cook, R.D. and Weisberg, S. (1982). Residual and Influence in Regression, (Chapman and Hall).

Draper, N.R.and Smith, H. (1998). Applied Regression Analysis, (3rd Ed.Wiley).

Gunst, R.F.and Mason, R.L. (1980). Regression Analysis and Its Applications- A Data Oriented Approach, (Marcel and Dekker).

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Weisberg, S. (1985). Applied Linear Regression., (Wiley).

ST-206: PRACTICALS-II

A. Practicals based on Probability Theory. (5 Hours, 4 Marks)

1. Plotting c.d.f. (1L)
2. Applications and verification WLLN. (2L)
3. Applications and verification of CLT. (2L)

B. Practicals based on Stochastic Processes. (12 Hours, 8 Marks)

1. Calculation of n-step transition probabilities and limiting distribution in Markov chain. (2L)
2. Realization of Markov chain. (2L)
3. Realization of Branching process. (2L)
4. Simulation of Poisson process. (1L)
5. Simulation of Random Walk. (1L)
6. Simulation of Renewal process. (1L)
7. Simulation of $M \mid M \mid 1$ queuing system. (1L)
8. Estimation of transition probability of Markov chain using realization. (1L)
9. MCMC Techniques (1L)

C. Practicals based on Multivariate Analysis. (28 Hours, 18 Marks)

1. Model sampling from bivariate distributions (Bivariate exponential, Bivariate Poisson, Bivariate Poisson, Bivariate negative binomial, Bivariate binomial) (4L)
2. Model sampling from multivariate normal distribution (including conditional distribution) (4L)
3. Estimation of $\underline{\mu}, \Sigma$-matrix, correlation coefficient, multiple correlation coefficients. Test of significance of multiple and partial correlation coefficients. (4L)
4. Applications of Hotelling's T^2. (6L)
5. Discriminant Analysis and Classification problem. (4L)
6. Principal components. (2L)
7. Canonical Correlation. (2L)
8. MANOVA (2L)

D. Practicals based on Parametric Inference. (14 Hours, 10 Marks)

1. Sampling distribution of Statistics/ Estimators (3L)
2. Plotting likelihood functions for standard probability distributions. (3L)
3. Unbiased estimation, Moment Estimation, Maximum Likelihood Estimation (discrete, continuous, mixture, truncated distributions.) for parameters and parametric functions. (4L)
4. Power of the test, MP test, UMP test (for continuous, mixture and truncated distributions), Minimum sample size needed to attain given power. (3L)
5. Interval estimation (1L)

E. Practicals based on Linear Models and Regression Analysis.
(30 Hours, 20Marks)

1. Linear Estimation. (4L)
2. Analysis of CRD, RBD, LSD. (6L)
3. Test of hypotheses for one and more than one linear parametric functions. (4L)
4. Multiple Regression:
   - Estimation of regression coefficient, Fitting of multiple linear regression.(2L)
   - Testing of hypothesis concerning regression coefficient. (2L)
   - Testing of significance of association between the dependent and independent variables. (2L)
   - Lack of fit test, Extra sum of squares principle. (2L)
5. Orthogonal Polynomials: Fitting of orthogonal polynomials. (2L)
6. Residual Analysis. (2L)
7. Non-linear regression. (2L)
8. Logistic Regression. (2L)

NORTH MAHARASHTRA UNIVERSITY
JALGAON

SYLLABUS

FOR

M.Sc. STATISTICS
(Semester III and IV)

With specialization in Industrial Statistics

WITH EFFECT FROM ACADEMIC
YEAR 2013-2014

NORTH MAHARASHTRA UNIVERSITY, JALGAON
Syllabus for M.Sc.-II (Statistics)
with specialization in Industrial Statistics
(With effect from Academic Year 2013-2014)
Syllabus Structure

Semester-III

Course No.	Title of the Course	Contact hours / week			Marks Distributions for Examinations						Credits
					Internal		External		Total		
		Th(L)	Pr	Total	Th	Pr	Th	Pr	Th	Pr	
ST-301	Asymptotic and Nonparametric Inference	04	--	04	40	--	60	--	100	--	04
ST-302	Design, Planning and Analysis of Experiments	04	--	04	40	--	60	--	100	--	04
ST-303	Total Quality Management (TQM) Statistical Process Control (SPC) and Reliability	04	--	04	40	--	60	--	100	--	04
ST-304	Optional Course	04	--	04	40	--	60	--	100	--	04
ST-305	Practicals- III	--	06	06	--	40	--	60	--	100	04

Semester-IV

Course No.	Title of the Course	Contact hours / week			Marks Distributions for Examinations						Credits
					Internal		External		Total		
		Th(L)	Pr	Total	Th	Pr	Th	Pr	Th	Pr	
ST-401	Optimization Techniques	04	--	04	40	--	60	--	100	--	04
ST-402	Actuarial Statistics	04	--	04	40	--	60	--	100	--	04
ST-403	Optional Course	04	--	04	40	--	60	--	100	--	04
ST-404	Technical Communications and Practicals-IV	--	06	06	--	40	--	60	--	100	04
ST-405	Project	--	06	06	--	--	--	100	--	100	06

Th: Theory **Pr: Practicals/Project** **L: Lectures** **M: Marks**

List of optional courses to be offered in Semester-III

ST-304(A): Design and Analysis of Clinical Trials
ST-304(B): Financial Mathematics

List of optional courses to be offered in Semester-IV

ST-403(A): Time Series Analysis
ST-403(B): Statistical Simulations

Objectives

Main objective of this syllabus is to train students in depth in applied courses and projects in the area of Industrial Statistics which deals with Statistical analysis related to data from Manufacturing, Pharmaceutical, Software, Social Sciences, Financial and Actuarial fields. The course on Technical Communications will enhance their communication and presentation skills.

ST-301: ASYMPTOTIC AND NONPARAMETRIC INFERENCE

- Review of convergence in probability and convergence in distribution, Cramer and Slutsky's Theorems. (2L,2M)
- Consistent Estimation of real and vector parameter. Invariance of Consistent estimator under continuous transformation. (3L,3M)
- Consistency of estimators by method of moments, and method of percentiles, Mean squared error criterion. (4L,4M)
- Asymptotic relative efficiency, Error probabilities and their rates of convergence, Minimum sample sizes required to attain given level of accuracy. (4L,4M)
- Consistent Asymptotic Normal (CAN) estimator, Invariance of CAN estimator under differentiable transformation. (4L,4M)
- CAN property of estimators obtained by moments and percentiles. (3L,3M)
- CAN estimators obtained by moment and MLE method in one parameter exponential family, Extension of multi-parameter exponential family. (3L,3M)
- Examples of consistent but not asymptotically normal estimators. (2L,2M)
- Method of maximum likelihood, CAN estimators for one-parameter Cramer family, Cramer-Huzurbar theorem, Solution of likelihood equations, Method of scoring, Newton-Raphson and other iterative procedures. (6L,6M)
- Fisher Lower Bound to asymptotic variance, extension to multi-parameter cases (without proof.) Multinomial distribution with cell probabilities depending on a parameter. (3L,3M)
- MLE in Pitman Family and Double Exponential distribution, MLE in censored and truncated distribution. (3L,3M)
- Likelihood Ratio Test (LRT), asymptotic distribution of LRT statistic, Wald Test, Rao's score test, Pearson χ^2 test for Goodness of fit, Barlett's Test for homogeneity of variances. Large Sample Tests and confidence intervals based on CAN estimators, Variance stabilizing transformation and large sample tests. Consistency of Large Sample Tests. Asymptotic power of large sample tests. (8L,8M)
- Nonparametric Statistical Inference. (15L,15M)
  - Introduction to Nonparametric Inference.
  - U-Statistics.
  - Some Single-Sample problems.
  - Some Two-Sample problems.
  - Test of Independence.
  - Some Applications of Order Statistics.

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Dudewicz, E.J. and Mishra, S.N.(1988), Modern Mathematical Statistics. Wiley

ST-302: DESIGN, PLANNING AND ANALYSIS OF EXPERIMENTS

- Basic principles of design of experiments: Randomization, replications, local control. (2L,2M)
- Concept of Fixed effect models, Random effect models and Mixed effect models. (1L,1M)
- One way classification models, random effect model for one way classification. (5L,5M)
- Two way classification model with equal number of observations per cell with and without interactions. (6L,6M)
- General two way block designs, various characteristics of general two way block design: connectedness, balancedness and orthogonality, Balanced Incomplete Block Design (BIBD), PBIBD with two associate classes, LSD and Youden Square design. (10L,10M)
- Analysis of covariance (ANCOVA) in a general Gauss-Markov model, Applications and need of ANCOVA technique, Analysis of covariance in one-way and two-way classification model. (4L,4M)
- 2^k Full factorial designs: diagrammatic representation of main effects and first order interactions in the model, analysis of single as well as more than one replicates using ANOVA, technique of confounding, total and partial confounding in 2^k Full factorial designs and analysis of such designs. (5L,5M)
- Total confounding of 2^k design in 2^p blocks with $k > p \geq 2$, Partial confounding in 2^p blocks, p=2,3, analysis of designs with treatments confounded in more than two blocks. (5L,5M)
- Two-level-fractional factorial experiments, Resolution of a design (III, IV & V), abbreviation of a design, aliases, generators of the design, complete defining relation etc. (4L,4M)
- Concept of rotatable design. Central composite designs, 3^2 designs: contrasts for linear and quadratic effects, statistical analysis of 3^2 design. (5L,5M)
- Response surface methodology (RSM): linear and quadratic model, determination of stationary point, ridge systems, multiple responses, blocking in RSM, Plackett-Burman design. (5L,5M)
- Taguchi (orthogonal array) methods: concept of loss function, S/N ratio, Linear graphs ANOM inner and outer arrays, ANOVA. (8L,8M)

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Ogawa J.(1974) Statistical Theory of the Analysis of Experimental Design (Marcel Dekker).
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Kuehl R.O.(1994). Statistical Principals of Research Design and Analysis. Duxbury Press.

ST-303: TOTAL QUALITY MANAGEMENT (TQM), STATISTICAL PROCESS CONTROL (SPC) AND RELIABILITY

- Total Quality Management. (8L,8M)
  - Concept of Quality, Quality improvement, Quality philosophy.
  - Introduction of TQM, evaluation of Total Quality.
  - Some important TQM concepts.
  - TQM Gurus' Ideas.
  - Japanese 5-S Practice.
  - The Impact of National and International Quality Awards on TQM.
  - The European Quality Award.
  - The Deming Application Prize.
  - Six sigma and other Extensions of TQM.
  - Quality systems.
  - The ISO 9000 and other Quality systems.
- Review of some Statistical methods useful in Quality Improvement. (3L,3M)
  - Concept of variation, systematic variation, random variation, stable industrial processes.
  - Describing variation through graphical and numerical methods.
  - Some important Discrete and continuous probability distributions useful in quality control and improvement.
  - Some useful approximations of Distributions.
- Statistical Process Control (SPC).
  - Introduction of SPC. (3L,3M)
    - Basic concept of process monitoring and control.
    - Seven tools of SPC.
    - General theory of Control charts.
    - Different types of limits, Specification limits, Natural tolerance limits, Control limits, Warning limits.
    - OC Curve and ARL of control charts.
  - Control Charts for Attributes. (4L,4M)
    - Control chart for fraction nonconforming.
    - Control chart for fraction nonconformities (defects)
    - OC Curves for Attributes control charts.
  - Control Charts for Variables. (7L,7M)
    - Statistical basis of the charts for variables.
    - $\overline{X}$, R, S, $\overline{X}$ *and* R, $\overline{X}$ *and* S, $\overline{X}$ *and* S^2 Control Charts.
    - Median chart and Midrange chart.
    - Control charts for Individual Measurements.
    - Special control charts: CUSUM, EWMA control charts.
  - Process Capability Analysis. (8L,8M)
    - Capable process and Process capability.
    - Process Capability Analysis using Histogram or Probability plot.
    - Process Capability indices under normal distribution of quality characteristic.
      - Capability indices C_p, C_{pk}, C_{pm}.
      - Connection between proportion of nonconforming and C_p, C_{pk}.
      - Estimation, C.I. and tests of hypotheses relating to C_p.

- Process Capability Analysis for non-normal data.
- Process Capability Analysis for Designed Experiments.
- Gauge and Measurement system capability studies.
- Setting specification limits on discrete components, linear and nonlinear combinations.
- Estimating the Natural tolerance limits of a process.

- SPC for short production. (1L,1M)
- Modified and Acceptance control charts. (1L,1M)
- Group control chart. (1L,1M)
- SPC with autocorrelated process data (2L,2M)
- Multivariate Quality control. (2L,2M)
- Engineering process control(EPC) and SPC (2L,2M)
- Acceptance Sampling. (8L,8M)
  - Single, double and sequential sampling plans for attributes and their properties.
  - Curtailed double sampling plans, operating characteristics functions and other properties of the sampling plans.
  - Sampling plans with rectification. OC, ASN, ATI, AOQ curves, AOQL, Designing of sampling plan. Dodge-Romig acceptance sampling plans.
  - Plan for inspection by variables for one-sided and two-sided specifications; AQL based sampling plans.
- Elements of Reliability: (10L,10M)

  Components and systems, binary coherent structure k-out-of –n: G structure, bridge structure. Cuts and Paths, minimal path sets and minimal cut sets. Reliability of coherent system, bonds on system reliability. Structural and reliability importance of components, Hazard function, distribution with DFR and IFR.

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Mittag H.J. and Rinne H.(1993). Statistical Methods of Quality Assurance.

Barlow R.E. and Proschan F. (1985) Statistical Theory of Reliability and Life Testing; Holt, Rinehart and Winston.

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ST-304: Optional Course

List of optional courses to be offered for ST-304
(Detailed syllabus is given from page No.12)

ST-304(A): Design and Analysis of Clinical Trials
ST-304(B): Financial Mathematics

ST-305: PRACTICALS - III

(By using statistical software and/or Computer programming language)

A. Practicals based on course ST-301 (22 Hrs,15M)

1. Demonstrating consistency and CANness of consistent estimators.
2. Demonstration of consistency and asymptotic non-normality of estimator that is consistent but not CAN.
3. Computation of moment estimators and demonstration of their asymptotic distributions.
4. Verification of invariance property of consistent and CAN estimators under continuous transformation.
5. Generating consistent estimators by method of percentile.
6. MLE by methods of scoring.
7. Comparison of consistent estimator
   On the basis of their MSE's of different estimators.
   On the basis of requirement of minimum sample size.
8. ACI, Testing of hypothesis by likelihood ratio tests, computation and plotting of power function of test.
9. Fitting of distributions to sample data using following tests:
   Chi-square goodness of fit test
   Kolmogorov Smirnov goodness of fit test
   Lilliefor's goodness of fit test
10. Practical on one sample location problem
    (i) Sign test (ii) Wilcoxon Signed rank test
11. Practical on two sample location problem
    (i) Wilcoxon Rank sum test (ii) Mann Whitney U test
12. Practical on k sample Kruskal Wallis test, Friedman test.

B. Practicals based on course ST-302 (24 Hrs,15M)

1. Estimation of parameters, testing various hypothesis and analysis of variance for the following linear models:
   - Two-way classification model with r observations per cell with/without interaction.
   - Two-way classification model with unequal observations per cell
   - Random effect model for one-way classification model

2. Estimation of parameters, testing various hypothesis and analysis of covariance for the following linear models:

- One-way classification model with one or more than one concomitant variable.
- Two-way classification model with one or more than one concomitant variable.

3. Analysis of BIBD
4. Identification/verification of various properties (balancedness/connectedness, orthogonality) of the given design.
5. Generation and analysis of two-level factorial designs, main effect and interaction plots.
6. Analyzing two-level factorial designs with
   (i) Total confounding (ii) Partial confounding (iii) single replicate
7. Generation and analysis of two-level fractional factorial designs.
8. Analysis of 3^2 factorial design using response surface model (RSM), main effect and interaction plots.
9. Generating CCD and analysis of CCD with RSM, contour plots, response surface plots, calculation of stationary point and optimum response.
10. Generation and analysis of Taguchi orthogonal array designs.

C. Practicals based on course ST-303 (22 Hrs,15M)

1. Graphical tools used in SPC with their interpretations:
   Stem-and-leaf plot, Box plot, Histogram, Probability Plots, cause and effect diagram, Pareto chart, Scatter plot, Check sheet, Control chart.
2. accessing normality of data
3. Plotting and interpretation of Control chart for attribute.
4. Plotting and interpretation of Control chart for variable.
5. Plotting Multivariate Control chart.
6. Process capability analysis for normal data.
7. Process capability analysis for non-normal data.
8. Gauge capability analysis.
9. Control charts for Short Production Runs
10. Single and double sampling plans for attributes: plotting OC, ASN, ATI, AOQ curves, finding AOQL.
11. Single sampling plan for variables.
12. Calculation and/or estimation of reliability in parallel, series and k-out-of-n structures.

D. Practicals based on course ST-304 (22 Hrs,15M)

(About 10-12 practicals to be designed according to optional courses by the concerned teacher)

ST-401: OPTIMIZATION TECHNIQUES

- Mathematical Programming Problem. (1L,2M)
- Convex sets and functions. (3L,5M)
  Convex sets, supporting and separating hyper-plane, convex polyhedron, convex functions. Role of convex sets and function in Mathematical programming Problem.
- Linear Programming Problem (LPP). (6L,9M)
  Linear programming models, Graphical solution to LPP, Standard LPP (SLPP), basic solution and basic feasible solution to SLPP. Method for solving LPP: Simplex Algorithm, Two-phase simplex method, Charne's M-technique.
- Duality in LPP. (5L,5M)
  Dual LP, simplex multipliers and their interpretation with reference to dual variables. Duality theorems, Dual simplex method with justification, Post-optimality (sensitivity) analysis, Changes affecting feasibility and optimality. Economic interpretation of dual variables and dual constraints.
- Integer LPP (ILPP) (5L,6M)
  - Methods for ILPP: Gomory's algorithm for pure ILPP, branch and bound method.
  - Applications of ILPP.
- Quadratic Programming Problem (QPP). (5L,6M)
  Definition of QPP, Kuhn-Tucker conditions, Algorithms for solving QPP: Wolfe's and Beale's algorithm, Dual of QPP.
- Network Models. (5L,6M)
  Network definitions and applications. Shortest route problem and shortest-route algorithm-Dijkstra's algorithm. Maximal flow model and Maximal flow algorithm, Network representation, critical path computations.
- Probabilistic Inventory Models. (5L,6M)
  General Inventory model, Classic EOQ model-lead time, reorders point, Probabilitized EOQ model. Probabilistic EOQ model, single period model: No setup model and setup model (s-s policy), multiperiod model.
- Dynamic Programming (5L,5M)
  Nature of dynamic programming, Deterministic processes, Non-sequential discrete optimization-allocation problems, assortment problems. Sequential discrete optimization long-term planning problems, multistage production processes. Marketing systems, application of dynamic programming to marketing problems.
- Queuing Systems. (10L,10M)
  - Elements of queuing models, Role of exponential distribution in queuing models.
  - Classification of queuing models with standard notations.
  - Poisson Queuing models, Generalized Poisson Queuing model and their steady state distributions.
  - Steady state solutions of M/G/1, G/M/1 and M/D/C queuing models using imbedded Markov chain method.

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Kambo N. S. (1991) Mathematical Programming Techniques.
Hadley G. (1987) Linear Programming.
Taha H.A. (2002) Operations Research 6th ed. (Macmillan).
Panneerselvam, R. Operations Research (Prentic hall of India)
Medhi j. (1984) Stochastic Processes 2nd ed.(New Age International Pvt. Ltd.)

ST-402: ACTUARIAL STATISTICS

- Introduction to Insurance Business. (2L,2M)
- Insurance and utility theory. (3L,3M)
- Risk models for Insurance. (4L,5M)
  - Individual and aggregate Risk models for short term.
  - Distribution of aggregate claims, compound Poisson distribution and its applications. Distribution of aggregate claims, compound Poisson distribution and its applications.
- Survival function and Life tables. (8L,10M)
  - Survival function, Distribution function, Density functions and Force of mortality. Time-until-death random variable and Curtate-future lifetime random variable.
  - Life tables, Select and ultimate life tables.
  - Assumptions for fractional ages and some analytical laws of mortality.
- Life Insurance. (8L,10M)
  - Principles of compound interest: Nominal and effective rates of interest and force of interest and discount, compound interest, accumulation factor, continuous compounding.
  - Insurance payable at the moment of death and at the end of the year of death, level benefit insurance, Whole life insurance, endowment insurance, deferred insurance and varying benefit insurance.
  - Recursion equations and commutation functions.
- Annuities. (8L,8M)
  Annuities certain, Continuous and Discrete life annuities. Life annuities with m-thly payments and approtionable annuities. Recursion equations.
- Net premium. (8L,8M)
  - Fully continuous and discrete premiums.
  - True m-thly payment premiums, apportionable premiums and accumulation type benefits. Insurance model including expenses.
- Reserve. (5L,6M)
  Prospective and retrospective reserve. Fully continuous and discrete net premiums reserves. Reserves on a semicontinuous basis and true m-thly premiums. Reserves on an apportionable or discounted continuous basis. Recursive formulates and differential equations for reserves commutation functions.
- Multiple life functions. (3L,4M)
  Joint life and last survivor status, insurance and annuity benefits through multiple life functions evaluation for special mortality laws.
- Multiple decrement models. (4L,4M)
  Deterministic and random survivorship groups associated single decrement tables, central rates of multiple decrement, net single premiums and their numerical evaluations.

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Robin Cunningham, Thomas N. Herzog, Richard L. Models for Quantifying Risk, 4th Edition, ACTEX Publications, 2011.

Browers, Newton L et al., Actuarial Mathematics 2nd . Society of Actuaries, 1997.

Dickson, David C. M., Hardy, Mary R. and Waters, Howard R., Actuarial Mathematics for life contingent risks, International series on actuarial science, Cambridge 2009.

Deshmukh S. R., An Introduction to Actuarial Statistics, University Press, 2009

ST-403: Optional Course

List of optional courses to be offered for ST-403
(Detailed syllabus is given from Page No.15)

ST-403(A): Time Series Analysis
ST-403(B): Statistical Simulations

ST-404: TECHNICAL COMMUNICATIONS AND PRACTICALS-IV

Technical Communications (40 marks Internal Evaluation)

- **Lectures on:** **(14 Hrs, 10M)**
    - Technical and official communication skills.
    - Communication/presentation skills of the student.

- **Seminars by Students(to be assessed by teacher(s))** **(20 Hrs, 30M)**
  Each student will have to prepare his/her presentation/lecturer based on any topic from Statistics and deliver / present it before all students and teachers of the department..

Practicals-IV (60 marks External Practical Examination)
(Based on software and computer programming)

A. Practicals based on course ST-401 **(14 Hrs,14M)**

1. Getting basic feasible solution to given LPP.
2. Graphical solution to LPP with 2 decision variables.
3. Solving the primal LP (or dual LP) by using following methods.
    i) Simplex algorithm.
    ii) Simplex method.
    iii) Charne's Big-M method.
    iv) Dual simplex method.
4. Getting optimal solution for dual LP (without solving DLP) using optimal solution for primal LP.
5. Calculation of Simplex multipliers for given LPP.
6. Solving Quadratic programming problem using Kuhn-Tucker conditions.
7. Solving integer programming problem.
8. Practicals based on inventory models.
9. Simulation of various queuing models and verification of their steady state distributions.

B. Practicals based on course ST-402 **(21 Hrs,23M)**

1. Calculation of simple interest and compound interest.
2. Relation between nominal, effective and force of interest.
3. Plotting of utility functions.
4. Distribution of total claim in short term risk models.
5. Construction of life tables and Problems based on life tables
6. Life table using analytical laws of mortality.
7. Annuity immediate and due.
8. Calculation of premiums.
9. Calculation of reserves.
10. Multiple life functions.

C. Practicals based on course ST-403 **(21 Hrs,23M)**
(To be formulated by concerned teacher based on optional course.)

ST-405: PROJECT

- **Project duration:** 25th November to 30th April. (Students may start preliminary work related to their project after second semester).
- **Project Guide:** Teachers from the Department of Statistics and/or personnel from organization where student is going to visit for field work or training. Each project group will be guided by concerned teacher (guide) for one hour per week throughout the semester.
- **Fieldwork:** Students will be given one month period in December during last semester for their industrial work/data collection/survey or any other fieldwork involved in the project.
- **Project Topic:** Students in consultation with the guide will decide Project Topic/Area. Topic may be decided after completion of second or third semester. Project work may be carried out in a group of students depending upon the depth of fieldwork/problem involved.
- **Project report:** Project report should be submitted in typed form with binding by 5th May (or within 7/10 days after external theory examination). Project viva will be arranged in the 1st or 2nd week of May.
- **Project evaluation:** Project evaluation will be based on
  (i) Project report(60marks)
  (ii) Presentation by student or group of students. (20 marks)
  (iii) Viva voce (20 marks)

  Two examiners will evaluate project work.

Detailed syllabi of optional courses

ST-304(A): DESIGN AND ANALYSIS OF CLINICAL TRIALS

- Introduction to Clinical Trials(CTs) (4L,4M)
  - Need and ethics of CTs
  - History of CTs.
  - Regulatory process and Requirement.
  - Investigational New Drug Application.
  - New Drug Application.
  - Overview of Phases I to IV trials
- Basic Design Consideration. (5L,5M)
  - Introduction.
  - Patient Selection.
  - Selection Control.
  - Statistical Consideration.
- Randomization and Blinding. (6L,6M)
  - Randomization Models.
  - Randomization Methods.
  - Implementation of Randomization.
  - Generalization of Controlled Randomized Trials.
  - Blinding.
- Classification Clinical Trials. (5L,5M)
  - Multicenter Trial.
  - Active Control Trial.
  - Combination Trial.
  - Equivalence Trial.
- Bioavailability and Bioequivalence Studies. (6L,6M)
  - History of Bioavailability Studies.
  - Formulation and Routes of Administration.
  - Pharmacokinetic Parameter.
  - Clinically Importance Differences.
  - Assessment of Bioequivalence.
  - Decision Rules and Regulatory Aspect.
  - Statistical Consideration.
- Designs of Clinical Trials. (6L,6M)
  - Parallel Designs.
  - Crossover Designs.
  - Balanced Incomplete Block Designs
  - Titration Designs.
  - Enrichment Designs.
- Statistical Inference for Effects from a Standard 2x2 Crossover Design. (8L,8M)
  - The Carry-over Effect.
  - The Direct Drug Effect.
  - The Period Effect.
  - The Analysis of Variance.

- Analysis of Continuous Data. (6L,6M)
  - Estimation.
  - Test Statistics.
  - Analysis of Variance.
  - Analysis of Covariance.
  - Nonparametric.
  - Repeated Measure
- Analysis of Categorical Data. (6L,6M)
  - Statistical Inference for One Sample.
  - Inference for Independent Sample.
  - Ordered Categorical Data.
  - Combing Categorical Data.
  - Model-Based Method.
  - Repeated Categorical Data.
- Power and Sample size Determination. (4L,4M)
  - Hypothesis and Type I and Type II Errors.
  - Power and Relative Efficiency
  - Sample size Determination.
- Assumptions and Outlier Detection. (4L,4M)
  - Tests for Assumption.
  - The Definition of Outlying Observation.
  - Detection of Outlying Subject.
  - Detection of Outlying Observation.

LAB WORK for Practicals based on following topics (Use of software packages is desirable).

1. Demonstration of *p*-value, type I and type-II errors using Z-test, t-test, two sample t-test, paired t-test and its interpretation and role in testing of hypothesis in CTs.
2. Relation between sample size and power of the test.
3. Randomization Methods.
4. Statistical Analysis for Parallel Designs.
5. Statistical Analysis for Standard 2x2 Crossover Designs.
6. Analysis of continuous data based on repeated measures under CTs.
7. Nonparametric Tests.
8. Analysis of Categorical Data.
9. Outlier Detection in CTs.
10. Estimation of Pharmacokinetic parameters.

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J.L.Fleiss (1989) The Design and Analysis of Clinical Experiments. Wiley and Sons.
E.Marubeni and M.G.Valsecchi (1994). Analyzing Survival Data from Clinical Trials and Observational studies, Wiley and Sons.
Shein-Chung Chow and Jen-pei Liu, Design and Analysis of Clinical trial, Wiley and Sons.
Shein-Chung Chow and Jen-pei Liu, Design And Analysis of Bioavailability and Bioequvalence Studies,Marcel Dekker,Inc

ADDITIONAL REFERENCES

S.Paintadosi.(1997) Clinical Trials: A Methodologic Perspective. Wiley and Sons.
L.M.Friedman, C.Furburg, D.L.Demets (1998). Fundamentals of Clinical Trials, Springer Verlag.

ST-304(B): FINANCIAL MATHEMATICS

- The measurement of interest: (8L, 8M)
  Introduction, The accumulation and amount functions, The effective rate of interest, Simple interest, Compound interest, Present value, The effective rate of discount, Nominal rates of interest and discount, Forces of interest and discount, Varying interest, Summary of results.
- Solution of problems in interest: (6L, 6M)
  Introduction, The basic problem, Equation of value, Unknown time, Unknown rate of interest, Determining time periods, Practical examples.
- Basic annuities: (8L, 8M)
  Introduction, Annuity-immediate, Annuity-due, Annuity values on any date, Perpetuities, Unknown time, Unknown rate of interest, Varying interest, Annuities not involving compound interest.
- More general annuities: (8L, 8M)
  Introduction, Differing payment and interest conversion periods, Annuities payable less frequently than interest convertible, Annuities payable more frequently than interest convertible, Continuous annuities, Payments varying in arithmetic progression, Payments varying in geometric progression, More general varying annuities, Continuous varying annuities, Summary of results,
- Amortization schedules and sinking funds: (8L, 8M)
  Introduction, Finding the outstanding loan balance, Amortization schedules, Sinking funds, Differing payment periods and interest conversion periods, Varying series of payments, Amortization with continuous payments, Step-rate amounts of principal.
- Bonds and other securities: (8L, 8M)
  Introduction, Types of securities, Price of a bond, Premium and discount, Valuation between coupon payment dates, Determination of yields rates, Callable and putable bonds, Serial bonds, some generalizations, other securities, Valuation of securities.
- Yield rates: (8L, 8M)
  Introduction, Discounted cash flow analysis, Uniqueness of the yield rate, Reinvestment rates, Interest measurement of a fund, Time-weighted rates of interest, Portfolio methods and investment year methods, Short sales, Capital budgeting-basic technique and other technique.
- Stochastic approaches to interest: (6L, 6M)
  Concept of a stochastic interest rate model and the fundamental distinction between this and a deterministic model, Independent rates of interest, The lognormal model

LAB WORK for Practicals based on following topics by using software package

1. Calculation Present and accumulated value of simple and compound interest.
2. Relation between nominal, effective and force of interest.
3. Calculation of present and accumulated value of annuities.
4. Redemption of loan schedule.
5. Bonds and securities
6. Yield rates.
7. Stochastic interest rates

REFERENCES

1. Kellison Stephen G., The Theory of Interest, 3rd Edition. McGraw-Hill International Edition (2009).
2. UK Institute of Actuaries core reading for the subject CT1-Financial Mathematics.

ST-403(A): TIME SERIES ANALYSIS

- Time series as discrete parameter stochastic process. Auto covariance and autocorrelation functions and their properties. (8L,8M)
- Exploratory Time Series Analysis Tests for trend and seasonally. Exponential and Moving Average Smoothing. Holt and Winters smoothing. Forecasting based on smoothing, Adaptive smoothing. (8L,8M)
- Detailed study of the stationary processes: (1) Moving average (MA), (2) Auto regressive (AR) and (3) ARMA process. Discussions (without proof) of estimation of mean, auto covariance and autocorrelation functions under large sample theory. Partial autocorrelation function. Estimation of Parameters, Choice of AR and MA periods. Order selection for ARMA process, Forecasting ARMA processes, Residual analysis and diagnostic checking. (20L,20M)
- Introduction to spectral analysis of weakly stationary process. Periodogram and correlogram analyses. (6L, 6M)
- Nonstationary and Seasonal Time series Models: Unit-root in nonstationarity, Unit-root tests, Integrated ARMA (ARIMA) models, Box-Jenkins models. Estimation of ARIMA model parameters. Seasonal ARIMA (SARIMA) models (12L, 12M)
- Introduction to Conditional Heteroschedastic Models: Volatility models, ARCH and GARCH, Properties, Examples, Estimation & Forecasting, (6L, 6M)

LAB WORK for Practicals (Use of software package is desirable)

1. Exploratory Analysis.
2. Smoothing.
3. Numerical exercises on MA and AR models Forecasting.
4. Numerical exercises on ARMA and ARIMA models Forecasting.
5. Numerical exercises on Box-Jenkins models.
6. Residual analysis and diagnostic checking.
7. Periodogram analysis and interpretation.
8. Correlogram analysis and interpretation.
9. Numerical exercises on Non-Stationary time series models
10. Volatility models.

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Anderson. T.W. (1971). The Statistical Analysis of Time Series Wiley, N.Y.

Montgemory, D.C. Johnson L.A (1990) Forecasting and Time Series Analysis, McGraw Hill.

Kendall, Sir Maurice and Ord, J.K. (1990). Time Series (Third Edition), Edward Arnold.

Brockwell, P.J. and Davis R.A.(2006) Time Series: Theory and Methods (Second Edition) Springer-Verlag.

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Fuller, W.A (1996) . Introduction to Statistical Time series , John Wiley N.Y.

Granger, C.W.J. and Newbold (1984) Forecasting Economic Time Series, Third Edition, Academic Press.

Kendall, M.G. and Stuart A. (1966). The Advanced Theory of Statistics, Volume 3, Charles Griffing, London.

Koopmans, L.H. (1974), The Spectral Analysis of Time series, Academic Press.

ST-403(B): STATISTICAL SIMULATIONS

- Statistic simulations: generating random variables, simulating normal, gamma and beta random variables. Comparison of algorithms to generate random variables. Generating random variables from failure rates. (15L, 15M)

- Simulating multivariate distributions, MCMC methods and Gibbs sampler, simulating random fields, simulating stochastic process. Variance reduction technique: importance sampling for integration, control variates and antithetic variables. (15L, 15M)

- Simulating a non-homogeneous Poisson process, Optimization using Monte Carlo methods, simulated annealing for optimization. Solving differential equations by Monte Carlo methods. (15L, 15M)

- Jackknife and Bootstrap. Bootstrap methods: re-sampling paradigms, bias and standard errors, Bootstrapping for estimation of sampling distribution. Confidence intervals, variance stabilizing transformation, bootstrapping in regression and sampling from finite populations. (15L, 15M)

REFERENCES

Fishman, G.S. (1996) Mante Carlo: Concepts, Algorithms and Applications. (Springer).

Rubinstein, R.Y. (1981); Simulation and the Monte Carlo Method. (Wiley).

Ripley, B.D. (1987) Stochastic Simulations (Wiley).

Ross, S. M. (2002) Simulation (Third Edition) (Academic).

Efron,B. and Tibshirani. R.J. (1993); An introduction to the Bootstrap.

Davison, A.C. and Hinkley,D.V. (1997) Bootstrap methods and their applications (Chapman and Hall).

Sho.J and Tu,D (1995); The Jackknife and the Bootstrap. Springer Verlag.