University of Kalyani

Department of Statistics

STRUCTURE AND DETAILED CURRICULUM FOR
SEMESTER-BASED
2-Year M. Sc. Course in Statistics
(Under NEP-2020)

With Effect from 2026-27

COURSE STRUCTURE

T: Theory, Pr: Practical, Tu: Tutorial; MJ: Major, SEC: Skill Enhancement Course, DSE: Discipline Specific Elective, RP: Research Project

2-Year M. Sc. in Statistics: SEMESTER 1

Paper Code	Paper Name	T + (Pr/Tu)	Credit	Marks Distribution			Total
				Theory	Pr/Tu	Internal	
2-ST-MJ-1.1	Real Analysis	T+Tu	4	40	10	10	60
2-ST-MJ-1.2	Measure Theory and Probability	T+Tu	4	40	10	10	60
2-ST-MJ-1.3	Sampling Distribution	T+Tu	4	40	10	10	60
2-ST-MJ-1.4	Stochastic Process	T+Pr	4	40	10	10	60
2-ST-MJ-1.5	Sample Survey	T+Pr	4	40	10	10	60
Total			20	200	50	50	300

2-Year M. Sc. in Statistics: SEMESTER 2

Paper Code	Paper Name	T + (Pr/Tu)	Credit	Marks Distribution			Total
				Theory	Pr/Tu	Internal	
2-ST-MJ-2.1	Asymptotic Theory	T+Tu	4	40	10	10	60
2-ST-MJ-2.2	Theory of Estimation	T+Pr	4	40	10	10	60
2-ST-MJ-2.3	Theory of Hypothesis Testing	T+Pr	4	40	10	10	60
2-ST-MJ-2.4	Decision Theory	T+Pr	4	40	10	10	60
2-ST-MJ-2.5	Nonparametric Methods	T+Pr	4	40	10	10	60
2-ST-MJ-2.6	Design of Experiments	T+Pr	4	40	10	10	60
Total			24	240	60	60	360

2-Year M. Sc. in Statistics: SEMESTER 3

Paper Code	Paper Name	T + (Pr/Tu)	Credit	Marks Distribution			Total
				Theory	Pr/Tu	Internal	
2-ST-SEC-3.1	Research Methodology & IKS	T+Tu	4	40	10	10	60
2-ST-MJ-3.2	Advanced Regression Analysis	T+Pr	4	40	10	10	60
2-ST-MJ-3.3	Reliability and Life Testing	T+Pr	4	40	10	10	60
2-ST-MJ-3.4	Operations Research	T+Pr	4	40	10	10	60
2-ST-SEC-3.5	Python Programming	Pr	4	0	50	10	60
Total			20	160	90	50	300

2-Year M. Sc. in Statistics: SEMESTER 4

Paper Code	Paper Name	T + (Pr/Tu)	Credit	Marks Distribution			Total
				Theory	Pr/Tu	Internal	
2-ST-MJ-4.1	Multivariate Techniques	T+Pr	4	40	10	10	60
2-ST-MJ-4.2	Artificial Intelligence and Machine Learning	T+Pr	4	40	10	10	60
2-ST-DSE-4.3	To be offered from the list	T+Pr	4	40	10	10	60
2-ST-DSE-2.4	To be offered from the list	T+Pr	4	40	10	10	60
2-ST-RP-2.5	Project	Pr	8	0	100	20	120
Total			24	160	140	60	360

Semester 1

2-ST-MJ-1.1 Real Analysis (Marks-60, Credit-4)

Introduction to real number, cluster points of sets, closed and open sets, compact sets, Bolzano-Weierstrass theorem, Heine-Borel theorem.

Real valued functions. Limit, continuity and uniform continuity, Differentiability of univariate and multivariate functions. Mean value Theorems, Extreme of functions.

Riemann Integral. Improper integrals. Riemann – Stieltjes integral. Sequence and series of functions, uniform convergence, Power series, Taylor's Series.

Convex functions and related properties

References:

1. Apostol, T.M. (1985): Mathematical Analysis, Narosa.
2. Rudin, W. (1976): Principles of Mathematical Analysis, McGraw Hill.
3. Goldberg, R.R.: Methods of Real Analysis.

2-ST-MJ-1.2 Measure Theory and Probability (Marks-60, Credit-4)

Classes of sets, Fields, Sigma fields, Minimum Sigma field, Borel Sigma field in R, Sequence of sets, lim sup and lim inf of a sequence of sets. Measure, Probability Measure, Properties of a measure.

Measurable functions, Random variables, D.F., decomposition of D.F., Statement of correspondence theorem, Generating function and Characteristic function, Inversion theorem, Continuity theorem (statement only)

Integration of a measurable function with respect to a measure, Monotone convergence theorem, Fatou's lemma, Dominated Convergence Theorem.

Sequence of random variables, Almost sure convergence.

Borel-Cantelli lemma, Independence, Hajek-Reyni inequality, Kolmogorov inequality, strong law of large numbers.

Central Limit Theorem for iid random variables, CLT for a sequence of independent Random variables. Statements of Lindeberg-Feller &Liapounoff's theorem.

Product measure and Fubini's theorem (Statements only)

References:

1. A.K. Basu: Measure Theory & Probability.
2. B.R. Bhat: Modern Probability Theory.
3. P. Billingley: Probability & Measure.
4. J.F.C. Kingman & S.J. Taylor: Introduction to Measure and Probability.
5. R.G. Laha& V.K. Rohatgi : Probability Theory.
6. R. Ash: Real Analysis and Probability.
7. C.W. Burrill: Measure Theory & Probability
8. K.R. Parthasarathi: Introduction to Probability and Measure.

2-ST-MJ-1.3 Sampling Distribution (Marks – 60, Credit – 4)

Non-central chi-square, t and F distributions.	6L
Distribution of X'AX.	2L
Fisher-Cochran's Theorem and related results.	4L
Random sampling from Np (μ,Σ), MLE's of μ and Σ and their stochastic independence.	4L
Central Wishart distribution using Bartlett's decomposition and its properties with proofs.	8L
Distribution of Hotelling's T^2and MahalanobisD^2with applications.	4L
Distribution of sample multiple correlation coefficient.	4L
Distribution of partial correlation coefficient.	4L
Distribution of regression coefficient vector.	4L

References:

1. Rao, C.R.: Linear Statistical Inference and its Applications, Wiley.

2. Anderson, T.W.: Introduction to Multivariate Analysis.

3. Kshirsagar, A.M.: Multivariate Analysis.

4. Srivastava, M.S. and Khatri, C.G.: Introduction to Multivariate Statistics.

2-ST-MJ-1.4 Stochastic Process (Marks – 60, Credit – 4)

Introduction to Stochastic processes, classification of Stochastic processes according to state space and time domain, Markov chain with finite and countable state space, n-step transition probability and its limit, Chapman – Kolmogorov equation, Stationary distribution classification of states, Random Walk and gambler's ruin problem. 16L

Discrete state space continuous time Markov chain: Poisson process, birth and death process. 12L

Renewal Theory: Elementary renewal theory, statement and uses of key renewal theorem. 8L

Branching process: Galton – Watson branching process, probability of ultimate extinction. 8L

Continuous process: Brownian motion. 4L

References:

1. J. Medhi: Stochastic Processes.
2. S.M. Ross: Introduction to Probability Models.
3. Karlin and Taylor: A First Course in Stochastic Processes.
4. Hoel, Port & Stone: Introduction to Stochastic Processes.

2-ST-MJ-1.5 Sample Survey (Marks: 60, Credit: 4)

Concepts of sampling design, sampling scheme and sampling strategy; inclusion probabilities; Horvitz–Thompson estimator of population total and mean; unequal probability sampling with and without replacement; Probability Proportional to Size (PPS) sampling; Hansen–Hurwitz estimator; mean per distinct unit estimator under SRSWR; Des Raj estimator; Murthy's estimator

and underlying principle; Rao–Hartley–Cochran sampling scheme; Hartley–Ross unbiased ratio estimator. 16 L

Sampling and sub-sampling of clusters; two-stage sampling with unequal numbers of second-stage units; ratio estimation in two-stage sampling; double sampling for stratification; double sampling for ratio and regression estimation; sampling on successive occasions; introduction to small area estimation. 12 L

Non-response in sample surveys; Hansen–Hurwitz callback method; Politz–Simmons' not-at-home method; randomized response techniques for qualitative and quantitative sensitive characteristics. 10 L

Variance estimation under unequal probability sampling; comparison of unequal probability estimators; symmetrized Des Raj estimator; efficiency considerations in advanced sampling designs; applications of advanced sampling methods in official statistics and large-scale national sample surveys. 10 L

References

1. Cochran, W. G. *Sampling Techniques*. Wiley.
2. Des Raj. *Sampling Theory*. McGraw-Hill.
3. Murthy, M. N. *Sampling Theory and Methods*. Statistical Publishing Society, Kolkata.
4. Mukhopadhyay, P. *Theory and Methods of Survey Sampling*. Prentice Hall of India.
5. Chaudhuri, A. and Mukerjee, R. *Randomized Response: Theory and Techniques*. Marcel Dekker.
6. Chaudhuri, A. and Stenger, H. *Survey Sampling: Theory and Methods*. Marcel Dekker.
7. Sinha, B. K. and Hedayat, A. S. *Design and Inference in Finite Population Sampling*. Wiley.
8. Sukhatme, P. V., Sukhatme, B. V., Sukhatme, S. and Asok, C. *Sampling Theory of Surveys with Applications*. Iowa State University Press and Indian Society of Agricultural Statistics.

Semester 2

2-ST-MJ-2.1 Asymptotic Theory (Marks – 60, Credit – 4)

Review of different modes of convergence, Scheffe's theorem, Slutsky's theorem. Characteristic function of random vector and the Multivariate CLT, Cramer Wold Device, δ-method of deriving the asymptotic distribution of a smooth function of an asymptotically normal sequence. Law of large numbers, Law of iterated logarithm. 20L

Sample statistics: Empirical distribution function (edf), strong consistency, asymptotic distribution of the edf. 6L

Quantiles: Consistency and asymptotic normality. 6L

Order Statistics: Relation to quantiles, asymptotic distribution of extreme order statistics. 6L

L-Statistic: Consistency and asymptotic normality due to Stigler (1974). 6L

Sample spacings: Uniform spacings, exponential spacings, general continuous spacings and extreme spacings. 4L

References:

1. P. Billingsley: Probability and Measure, Wiley.
2. C.R. Rao: Linear Statistical Inference and its Applications, Wiley.
3. R.J. Serfling: Approximation Theorems on Mathematical Statistics, Wiley.
4. S.S. Wilks: Mathematical Statistics, Wiley.
5. B. R. Bhatt: Modern Probability Theory, New Age International Publishers
6. E. L. Lehmann: Elements of Large Sample Theory, Springer.
7. T. S. Ferguson: A First Course in Large Sample Theory.
8. T. K. Chandra: A First Course in Asymptotic Theory of Statistics.
9. AW van der Vaart: Asymptotic Statistics.

2-ST-MJ-2.2 Theory of Estimation (Marks – 60, Credit – 4)

Sufficiency minimal Sufficiency, Factorization theorem in the dominated case (without proof), completeness, ancillary statistic, Basu's theorem. Unbiased estimation, Lehmann-Scheffe theorem, Chapman-Robbins inequality, Rao-Cramer Lower bound in the multiparameter case (statement only), Bhattacharyya inequality. 16L

Equivariant estimation with emphasis on location and scale, minimum risk equivariant estimators, Pitman estimator. 8L

Large sample considerations: consistency of estimators, consistency of the minimum likelihood estimator under Cramer type conditions, asymptotic normality of the one-step MLE, method of scoring (including the multiparameter set–up in all cases), asymptotic efficiency, Hodges' example, Bahadur's theorem on supper – efficient estimators (without proof). 12L

Resampling procedures in the context of estimation: the jackknife and bootstrap. 6L

Concept of robustness, Influence function and M-estimators. 6L

References:

1. Goon A.M., Gupta M.K., and Dasgupta, B.: An Outline of Statistical Theory, Vol 2, World Press.

2. Lehmann, E.L. and Casella, G.:Theory of Point Estimation, 2nd Ed, John Wiley.

3. Rao, C. R. (1973): Linear Statistical Inference & its Applications, Wiley. 12

4. Shao, J and Tu, D. (1995): The Jack Knife and Bootstrap, Springer.

2-ST-MJ-2.3 Theory of Hypothesis Testing (Marks-60, Credit-4)

Neyman-Pearson lemma, monotone likelihood ratio property, one-sided hypothesis against a one sided alternative, generalized Neyman-Pearson lemma (without proof), two sided hypothesis in a one parameter exponential family, least favourable distributions.

Locally best test (One sided), similar test, Neyman structure, UMPU test for a one-parameter exponential family.

Likelihood Ratio test (LRT), Asymptotic distribution of LRT statistics under simple null hypothesis (real parameter only), Wald's test and Rao's score test, consistency of the LR test for simple hypothesis, Bartlett's test for homogeneity of variances.

Confidence sets: relation with hypothesis testing; optimum confidence intervals.
Sequential tests, SPRT and its properties, fundamental identity, OC and ASN, Wald's equation for ASN.

References:

1. Lehmann, E.L.: Testing Statistical Hypotheses.

2. Ferguson, T.S.: Mathematical Statistics-A Decision Theoretic Approach.
3. Rohatgi, V.: An Introduction to Probability and Mathematical Statistics.
4. Rao, C.R.: Linear Statistical Inference and its Applications.
5. Kendall, M.G. and Stuart, A.: The Advanced Theory of Statistics, Vol. II.
6. Goon, A.M., Gupta M.K. and Dasgupta, B.: An Outline of Statistical Theory, Vol II.

2-ST-MJ-2.4 Decision Theory (Marks: 60, Credit: 4)

Elements of statistical decision problems; states of nature, action space, loss function, risk function and decision rules; randomized and non-randomized decision rules; statistical games and two-person zero-sum games; point estimation and hypothesis testing as decision problems; admissible decision rules; complete, essentially complete, minimal complete and minimal essentially complete classes of decision rules; completeness based on sufficient statistics; Rao–Blackwell theorem (statement only). 12 L

Prior, likelihood and posterior distributions; Bayes risk and Bayes decision rules; extended Bayes rules, generalized Bayes rules and limit of Bayes rules; risk set, lower boundary set ; admissibility of Bayes rules; minimax rules and computation of minimax rules; relation between admissible, Bayes and minimax rules; separating hyperplane theorem (statement only); existence and completeness of the class of Bayes rules; computation of minimax tests for one-sided hypotheses in monotone likelihood ratio (MLR) families. (16 Lectures)

Classical and Bayesian approaches to statistical inference; prior, likelihood and posterior distributions; conjugate and non-informative priors; Bayesian point estimation under common loss functions; posterior risk; credible intervals (introductory concepts); posterior predictive distributions; illustrative examples of one-parameter models using conjugate priors.(12 Lectures)

Decision-theoretic approaches to point estimation, hypothesis testing and classification problems; comparison of classical and Bayesian decision procedures; Bayesian decision rules in estimation and testing; applications of decision theory in reliability, quality control and medical decision making. (8 Lectures)

References

1. Ferguson, T. S. *Mathematical Statistics: A Decision Theoretic Approach*. Academic Press.
2. Berger, J. O. *Statistical Decision Theory and Bayesian Analysis*. Springer.
3. Lehmann, E. L. *Theory of Point Estimation*. Springer.

4. Robert, C. P. *The Bayesian Choice: From Decision-Theoretic Foundations to Computational Implementation*. Springer.
5. Ghosh, J. K., Delampady, M. and Samanta, T. *An Introduction to Bayesian Analysis: Theory and Methods*. Springer.
6. Lee, P. M. *Bayesian Statistics: An Introduction*. Wiley.
7. Hoff, P. D. *A First Course in Bayesian Statistical Methods*. Springer.

2-ST-MJ-2.5 Nonparametric Methods (Marks – 60, Credit – 4)

Empirical distribution function and quantile function, Kolmogorov-Smirnov goodness of fit test. 6L

One- and two-sample U-statistics, statement of the asymptotic normality of U-statistics, linear rank statistics, statement of the asymptotic normality under the hypothesis. 10L

One-sample location and scale problems, paired sample problems,Sign test, Wilcoxon signed rank test, two-sample homogeneity problem, Location and scale alternatives in the two-sample problem, Wilcoxon rank-sum test,Mann-Whitney tests,median test, Mood's test and the normal and inverse normal scores tests. 16L

Runs test for randomness,Wald-Wolfowitz runs test. 4L

One-way and two-way classification, Kruskal-Wallis and Friedman's tests. 4L

Measures of rank correlation: Spearman's rho and Kendall's tau. 4L

Confidence intervals related to the Median and the Mann-Whitney tests in one and two-sample problems. 4L

References:

1. Gibbons, J.D.& Chakraborti, S.: Nonparametric Statistical Inference.
2. Goon, A.M., Gupta, M.K., Dasgupta, B.: An Outline of Statistical Theory, Vol.2.
3. Hollander, M., Wolfe, D.A.: Nonparametric Statistical Methods.
4. Wasserman, L.: All of Nonparametric Statistics.

2-ST-MJ-2.6 Design of Experiments (Marks: 60, Credit: 4)

Concepts of connectedness, orthogonality and variance balance; intrablock analysis of incomplete block designs; Balanced Incomplete Block Designs (BIBD)—parameters, existence conditions, properties and analysis; recovery of interblock information and its applications in BIBD; justification of missing plot techniques. 14 L

Construction of Balanced Incomplete Block Designs (BIBD); Partially Balanced Incomplete Block Designs (PBIBD)—association schemes, properties and analysis; lattice designs; dual and linked block designs; resolvable BIBDs; Youden square designs; introduction to finite (Galois) fields and their applications in the construction of mutually orthogonal Latin squares, BIBDs and orthogonal arrays (prime power case); construction of mutually orthogonal Latin squares (prime power case). 12 L

Symmetrical factorial experiments; confounding and balance in symmetric factorial designs (prime power case); construction and analysis of confounded factorial designs; fractional factorial designs; orthogonal arrays and balanced arrays; examples of and designs (without proof). 12 L

Introduction to response surface methodology; first-order response surface designs; orthogonality, rotatability and blocking; Central Composite Designs (CCD); Box–Behnken Designs; applications of response surface methodology. 10 L

References

1. Chakrabarti, M. C. *Mathematics of Design and Analysis of Experiments*.
2. Kempthorne, O. *The Design and Analysis of Experiments*. John Wiley & Sons.
3. Cochran, W. G. and Cox, G. M. *Experimental Designs*. John Wiley & Sons.
4. Federer, W. T. *Experimental Design: Theory and Application*.
5. Das, M. N. and Giri, N. C. *Design and Analysis of Experiments*. Wiley Eastern Ltd.
6. Dey, A. *Theory of Block Designs*. Wiley Eastern Ltd.
7. John, P. W. M. *Statistical Design and Analysis of Experiments*. Macmillan.
8. Nigam, A. K., Puri, P. D. and Gupta, V. K. *Handbook of Analysis of Experimental Designs*.
9. Montgomery, D. C. *Design and Analysis of Experiments*. John Wiley & Sons.
10. Myers, R. H., Montgomery, D. C. and Anderson-Cook, C. M. *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*. Wiley.
11. Box, G. E. P. and Draper, N. R. *Response Surfaces, Mixtures, and Ridge Analyses*. Wiley.
12. Khuri, A. I. and Cornell, J. A. *Response Surfaces: Designs and Analyses*. CRC Press.

SEMESTER 3

2-ST-SEC-3.1: Research Methodology & IKS (Marks: 60, Credit: 4)

Foundations of Research Methodology: Meaning, objectives and motivation of research; scientific method;deductive and inductive reasoning; concepts of theory, empiricism, hypothesis, variables and research questions; identification and formulation of research problems; research design; qualitative and quantitative research; exploratory, descriptive and experimental research; sampling and questionnaire design; preparation of research proposals. 12L

Scientific Writing, Publication Ethics and Research Evaluation : Structure of a scientific paper; abstract, introduction, methodology, results, discussion, references and acknowledgements; preparation of review articles, book chapters, posters and conference presentations; plagiarism, fabrication, falsification and publication misconduct; authorship and conflict of interest; COPE guidelines; similarity checking software;reference management software (Mendeley, Zotero, EndNote); indexing databases (Scopus, Web of Science, Google Scholar); citation metrics (Impact Factor, h-index, CiteScore, SNIP, SJR); predatory journals and conferences; UGC-CARE and responsible research assessment. 14L

Indian Knowledge System (IKS) in Statistics and Mathematical Sciences: Introduction to the Indian Knowledge System; evolution of mathematical and statistical ideas in ancient and medieval India; contributions of Pingala, Aryabhata, Brahmagupta, Bhaskara II, Madhava of the Kerala School and Hemachandra; combinatorics,binomial coefficients and the Meru Prastāra (Pascal triangle); probability ideas in ancient Indian games and literature; statistics in the Arthashastra and ancient administrative systems; history of census and official statistics in India; contributions of P. C. Mahalanobis, R. C. Bose, C. R. Rao, S. N. Roy, D. B. Lahiri, and the Indian Statistical Institute; role of statistics in national planning and development. 14L

Statistical Literature Review: Literature survey using scientific databases; critical reading of statistical journal articles; preparation of literature reviews; reviewing classical and

contemporary statistical papers, preparation of technical reports and project reports; research communication. 10L

Reference

1. C. R. Kothari – Research Methodology: Methods and Techniques
2. Robert A. Day & Barbara Gastel – How to Write and Publish a Scientific Paper
3. Michael Alley – The Craft of Scientific Writing
4. Wayne C. Booth et al. – The Craft of Research
5. Nicholas Walliman – Research Methods: The Basics
6. Pandey & Pandey – Research Methodology: Tools and Techniques
7. Sugimoto & Larivière – Measuring Research
8. Springer Handbook of Science and Technology Indicators
9. Kapil Kapoor & Avadesh Kumar Singh – Indian Knowledge Systems
10. B. Mahadevan – Introduction to Indian Knowledge System
11. C. R. Rao — Statistics and Truth
12. J. K. Ghosh — Statistical Thought: A Perspective and History (selected chapters)
13. C. R. Rao. — Statistics: Reflections and Memories

2-ST-MJ-3.2 Advanced Regression Analysis (Marks – 60, Credit – 4)

Classical Linear Regression Model: Polynomial regression models, Multicollinearity, Regularization techniques: Ridge, Lasso, Elastic net. 6L

Generalized Linear Models (GLM): Concept of GLM, link function, estimation of parameters. Models for binary data: logistic, probit. Models for multinomial data: multinomial logit. Models for ordinal data: cumulative logit. Models for count data: Poisson regression, negative binomial regression. 18L

Linear mixed model: Multilevel data, linear mixed model, estimation of parameters, EM algorithm. 8L

Spatial Regression: Spatial Data, spatial autocorrelation, LM diagnostics, spatial lag model, spatial error model, Geographically Weighted Regression (GWR). 12L

Quantile Regression: Basic concept, quantile regression model, estimation of parameters. 4L

Reference:

1. McGullagh, P and Nelder, J.A. (1989), Generalized Linear Models, London: Chapman and Hall.
2. Agresti, A. (2015), Foundations of Linear and Generalized Linear Models, Wiley Series in Probability and Statistics.
3. Agresti, A. (2012), Categorical Data Analysis, 3rd edition, Wiley Series in Probability and Statistics.
4. Dobson & Barnett (2008), An Introduction to Generalized Linear Models, Taylor & Francis.
5. Hastie, T., Tibshirani, R., Friedman, J.H. and Friedman, J.H. (2009): The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Vol 2.
6. Anselin, L.: Spatial Econometrics: Methods and Models.
7. Haining, R (2003): Spatial Data Analysis: Theory and Practice.
8. Seymour, L. (2005). Spatial Data Analysis: theory and practice.
9. Koenker, R: Quantile Regression.

2-ST-MJ-3.3 Reliability and Life-testing (Marks – 60, Credit – 4)

System Reliability: Reliability concepts and measures; components and systems, coherent systems; reliability of coherent systems; cuts and paths; modular decomposition; bounds on systems reliability and reliability importance of components. 8L

Basic Quantities and Models: Life distributions, survival functions, hazard rate, residual life time, mean residual life function, one-one correspondence of these functions, common life distributions, exponential, Weibull, gamma, Makeham, Pareto, Rayleigh, lognormal etc. 6L

Notion of Aging: IFR, IFRA, DMRL, NBU, NBUE, HNBUE classes and their duals for continuous and discrete setups. Exponential distribution and its non-ageing property. 6L

Life Testing: Censoring and Truncation. Type-I, Type-II and Random Censoring. Maximum likelihood estimation under random censoring, method of scoring. Tests based on MLE, Wald type test, LR test and Score test. Hybrid censoring, Progressive Type-II censoring, Progressive Type-I interval censoring and related inference. 10L

Multivariate Reliability: Vector concept of hazard rate, multivariate lack of memory property, properties of multivariate exponential distribution due to Marshall and Olkin. Other multivariate exponential and Weibull distributions. Inference under random censoring for bivariate cases. Multivariate reliability analysis using Copula, Sklar's Theorem, Series and Parallel systems for dependent components. 10L

Reliability Engineering: Univariate shock models, repairable systems, redundancy optimization, Stress-Strength Reliability and Accelerated Life tests. 8L

Reference:

1. Barlow, R. E., and Proschan, F.: Statistical Theory of Reliability and Life Testing, Holt, Rinehart and Winston.
2. Barlow, R. E., and Proschan, F.: Mathematical Theory of Reliability, SIAM.
3. Lawless, J. F.: Statistical Models and Methods of Lifetime Data, Wiley.
4. Mukherjee, S. P. and Nanda, A. K.: Probability Models in Reliability Analysis, Springer.
5. Finkelstein, M. and Cha, J. H.: Stochastic Modeling for Reliability, Springer.
6. Rausand, M. and Hoyland, H.: System Reliability Theory Models, Statistical Methods and Applications, Wiley.
7. Kapur, K. C. and Lamberson, L. R.: Reliability in Engineering Design, Wiley.
8. Bain, Lee, J. and Max Engelhardt: Statistical Analysis of Reliability and Life-Testing Models: Theory and Methods, Marcel Decker.
9. Rigdon, S. E. and Basu, A. P.: Statistical Methods for the Reliability of Repairable Systems, Wiley.

2-ST-MJ-3.4 Operations Research (Marks – 60, Credit – 4)

Definition and scope of OR. Phases in OR. 2L

Review of linear programming problem, methods of solution, duality of LPP, transportation and assignment problems with proof of relevant results, travelling salesman problem. 12L

Inventory control- Classical inventory model, EOQ model with price breaks, Probabilistic EOQ models. 10L

Queueing systems- Generalized Poisson queueing model, specialised Poisson queues such as (M/M/1) : (GD/∞/∞), (M/M/1) : (FIFO/∞/∞), (M/M/c) : (GD/∞/∞) etc. 8L

Simulation- Monte-Carlo method, generation of random observations from a few standard distributions. 6L

Information theory- Communication processes, entropy as a measure of information, marginal and joint entropy, mutual information with proofs of relevant results. Axiom of entropy. Encoding, Shannon-Fano procedure. Differential entropy and Kullback-Leibler divergence, relationship with Fisher Information. Maximum entropy distributions under different moment constraints. 10L

Reference:

1. Taha, H.A.: Operations Research: An Introduction, 6th Ed. 1997 Prentice–Hall of India.
2. Hadley, G. (1962): Linear Programming, Addison-Wesley.
3. Gass, S. (1958): Linear Programming: Methods and Applications, McGraw-Hill.
4. Goel and Mittal: Operations Research, Sultan Chand.
5. Kanti Swarup, P.K. Gupata & M.M. Singh (1985): Operations Research, Sultan Chand.
6. Cover, T. M., & Thomas, J. A. (2006). Elements of Information Theory. John Wiley & Sons, Hoboken, New Jersey.

2-ST-SEC-3.5 Python Programming (Marks – 60, Credit – 4)

Introduction 6L

Structure of a Python Program, Elements of Python, Python Interpreter, Using Python as calculator, Python shell, Indentation. Atoms, Identifiers and keywords, Literals, Strings, Operators (Arithmetic operator, Relational operator, Logical or Boolean operator, Assignment, Operator, Ternary operator, Bit wise operator, Increment or Decrement operator).

Creating Python Programs 6L

Input and Output Statements, Control statements (Branching, Looping, Conditional Statement, Exit function, Difference between break, continue and pass.), Defining Functions, default arguments, Errors and Exceptions.

Iteration and Recursion 5L

Conditional execution, Alternative execution, Nested conditionals, The return statement, Recursion, Stack diagrams for recursive functions, Multiple assignment, The while statement, Tables, Two-dimensional tables.

Strings and Lists 6L

String as a compound data type, Length, Traversal and the for loop, String slices, String comparison, A find function, Looping and counting, List values, Accessing elements, List length, List membership, Lists and for loops, List operations, List deletion. Cloning lists, Nested lists.

Object Oriented Programming 6L

Introduction to Classes, Objects and Methods, Standard Libraries.

Data Structures 4L

Arrays, list, set, stacks and queues.

Searching and Sorting 5L

Linear and Binary Search, Bubble, Selection and Insertion sorting.

Python for Data science 6L

Introduction to NumPy, SciPy, Matplotlib and Pandas. Scikit-learn.

Idea of Parallel Computing and Efficient Programming. 4L

References :

1. T. Budd, Exploring Python, TMH, 1st Ed, 2011
2. How to think like a computer scientist : learning with Python / Allen Downey,
3. Jeffrey Elkner, Chris Meyers. 1st Edition – Freely available online.2012

Semester 4

2-ST-DSE-4.1 Multivariate Techniques (Marks-60, Credit-4)

Multivariate normal distribution and its properties, MLEs of parameters.Distribution of sample mean vector, Wishart matrix-its distribution (with out derivation) and properties, Null distribution of Hotelling T^2 statistic and its application (including simultaneous confidence interval), Mahonalobis D^2 statistic.

Organization and representation of multivariate data.

Dimension Reduction Techniques :

a) Principal Component Analysis Concept, Computation, Large sample Inferences.

b) Canonical Correlation Analysis: Concept, Computation, Large sample, Inferences.

c) Exploratory Factor Analysis: Concept, Factor model, estimation of factor landings, factor rotation, estimating factor scores, Model fit.

Multivariate Analysis of Variance: One-way and two-way classified data with one observation per cell.

Discriminant Analysis: Likelihood ratio, Bayes and minimax procedures, Discrimination between two multivariate normal populations with common dispersion, Sample discriminate function, estimation, Fisher's method for discriminating among several populations.

Multidimensional Scaling: Classical Metric Scaling, Non-metric scaling.

References:

1. Johnson, R.A. and Wichern, D.W.: Applied Multivariate Statistical Analysis.
2. Kshirsagar, A.M. Multivariate Analysis.
3. Morrison, D.F. Multivariate. Statistical Methods.
4. Seber, G.A.F. Multivariate Observations.
5. Mardia, Kent and Bibby.

2-ST-MJ-4.2 Artificial Intelligence and Machine Learning (Marks – 60, Credit – 4)

Introduction to Machine Learning, Supervised and Unsupervised learning, Classification of problems – Regression and Classification. 6L

Linear Regression: Linear least squares regression, subset selection, shrinkage, Regularization: Ridge, Lasso and Elastic-net regression. 6L

Classification: Linear Discriminant Analysis (LDA), logistic regression, regularized logistic regression. 6L

Decision Tree, Random Forest. 6L

Neural Networks: Neural networks, Fitting neural networks, hidden units and layers. 6L

Support Vector Machines: Support vector classifier, SVM for classification, generalizing linear discriminant Analysis. 6L

Unsupervised learning: Introduction, k-Means Algorithm, Optimization objective. 6L

Gen AI and Large Language Model (LLM). 6L

Reference:

1. Hastie, T., Tibshirani, R., Friedman, J.H. and Friedman, J.H. (2009): The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Vol 2.
2. Kalita, J.K., Bhattacharya, D.K., Roy, S.: Fundamentals of Data Science: Theory and Practice.
3. James, G., Witten, D., Hastie, T. and Tibshirani, R.: *An Introduction to Statistical Learning: With Applications in R*. Springer.
4. Bishop, C. M.: *Pattern Recognition and Machine Learning*. Springer.
5. Alpaydin, E.: *Introduction to Machine Learning*. MIT Press.
6. Goodfellow, I., Bengio, Y. and Courville, A.: *Deep Learning*. MIT Press.
7. Russell, S. and Norvig, P.: *Artificial Intelligence: A Modern Approach*. Pearson.
8. Jurafsky, D. and Martin, J. H.: *Speech and Language Processing*. Pearson

Elective Papers: 2ST-DSE-4.3

2ST-DSE-4.3 Survival Analysis and Clinical Trials

Fundamentals of Survival Analysis: Introduction to survival analysis; survival, hazard and cumulative hazard functions; survival distributions and their applications—Exponential, Gamma, Weibull, Rayleigh and Lognormal distributions; bathtub-shaped hazard function; censoring and truncation; Type I, Type II, progressive and random censoring with biological examples; estimation of mean survival time under Type I and Type II censoring; non-parametric estimation of survival functions using Actuarial and Kaplan–Meier methods; comparison of survival curves using the Log-rank test. **16L**

Competing Risks and Regression Models: Competing risk theory; indices for measuring probabilities of failure under competing risks and their interrelations; estimation using maximum likelihood and modified minimum chi-square methods; independent and dependent competing risks; bivariate normal dependent risk model; introduction to Cox proportional hazards regression and hazard ratio. **10L**

Fundamentals of Clinical Trials: Introduction to clinical trials; phases of clinical trials (Phase I–IV); protocol development; control groups; placebo and active controls; ethical principles in clinical trials; informed consent; Good Clinical Practice (GCP); blinding and masking; sources of bias; sample size determination (basic concepts); monitoring and reporting of clinical trials. **12L**

Randomization Procedures in Clinical Trials: Randomized clinical trials; balancing treatment assignments; complete and restricted randomization; random allocation rule; truncated binomial design; Efron's biased coin design; Wei's urn design; covariate-adaptive randomization; response-adaptive randomization; ethical issues in adaptive randomization; applications in modern clinical trials. **10L**

References

1. Indrayan, A. Medical Biostatistics. 2nd Edition, Chapman & Hall/CRC.
2. Biswas, S. Applied Stochastic Processes: A Biostatistical and Population Oriented Approach. New Central Book Agency.
3. Lee, E. T. and Wang, J. W. Statistical Methods for Survival Data Analysis. 3rd Edition, John Wiley & Sons.
4. Chiang, C. L. Introduction to Stochastic Processes in Biostatistics. John Wiley & Sons.
5. Collett, D. Modelling Survival Data in Medical Research. Chapman & Hall/CRC.

6. Klein, J. P. and Moeschberger, M. L. Survival Analysis: Techniques for Censored and Truncated Data. Springer.
7. Friedman, L. M., Furberg, C. D., DeMets, D. L., Reboussin, D. M. and Granger, C. B. Fundamentals of Clinical Trials. Springer.
8. Rosenberger, W. F. and Lachin, J. M. Randomization in Clinical Trials: Theory and Practice. John Wiley & Sons.
9. Chow, S. C. and Liu, J. P. Design and Analysis of Clinical Trials: Concepts and Methodologies. John Wiley & Sons.
10. Chen, D.-G. (Din) and Peace, K. E. Clinical Trial Data Analysis Using R. Chapman & Hall/CRC.

OR

2ST-DSE-4.3 Actuarial Statistics

Probability Models and Life Tables : Introduction to actuarial science; utility theory and insurance; probability models for individual and aggregate claims; survival function, curtate future lifetime and force of mortality; life tables and their relationship with survival functions; complete and abridged life tables; select and ultimate life tables; assumptions for fractional ages; analytical laws of mortality including Gompertz and Makeham laws. **12 L**

Multiple Life Models and Risk Theory : Multiple life functions; joint life and last survivor status; multiple decrement models; deterministic and random survivorship groups; associated single decrement tables; central rates of multiple decrement; distribution of aggregate claims; compound Poisson distribution and its applications; introduction to stop-loss insurance and claim amount distributions. **12 L**

Life Insurance and Life Annuities: Principles of compound interest; nominal and effective rates of interest and discount; force of interest; accumulation and discount factors; life insurance contracts—term insurance, whole life insurance, endowment insurance, deferred insurance and varying benefit insurance; life annuities—continuous and discrete annuities, annuities-due and annuities-immediate, monthly payment annuities; commutation functions and recursive relationships. **14 L**

Premiums and Actuarial Reserves: Net premiums; continuous and discrete premium calculation; premium payment schemes; net premium reserves; continuous and discrete reserves; reserves at fractional durations; recursive reserve calculations; practical considerations in premium calculation including expense loadings; applications in life insurance and pension schemes. **10 L**

References:

1. Bowers, N. L., Gerber, H. U., Hickman, J. C., Jones, D. A. and Nesbitt, C. J. Actuarial Mathematics. Society of Actuaries, 2nd Edition.
2. Dickson, D. C. M., Hardy, M. R. and Waters, H. R. Actuarial Mathematics for Life Contingent Risks. Cambridge University Press.
3. Atkinson, M. E. and Dickson, D. C. M. An Introduction to Actuarial Studies. Elgar Publishing.
4. Neill, A. Life Contingencies. Heinemann.
5. Spurgeon, E. T. Life Contingencies. Cambridge University Press.
6. Gerber, H. U. Life Insurance Mathematics. Springer.
7. Rolski, T., Schmidli, H., Schmidt, V. and Teugels, J. Stochastic Processes for Insurance and Finance. John Wiley & Sons.
8. Bedford, T. and Cooke, R. Probabilistic Risk Analysis: Foundations and Methods. Cambridge University Press.
9. Philip, M., Booth, P., Chadburn, R., Cooper, D. and Haberman, S. Modern Actuarial Theory and Practice. Chapman & Hall/CRC.
10. Promislow, S. D. Fundamentals of Actuarial Mathematics. John Wiley & Sons.

OR

2ST-DSE-4.3 Public Health Statistics and Epidemiology

Health Statistics and Disease Measurement: Introduction to public health and epidemiology; measures of disease frequency: incidence, prevalence, attack rate and secondary attack rate; measures of mortality and morbidity; case fatality rate, standardized mortality ratio; disability-adjusted life years (DALYs) and quality-adjusted life years (QALYs); health indicators; sources of health data; national health surveys and health information systems. **12 L**

Epidemiological Study Designs: Observational and experimental studies; cross-sectional, ecological, case-control and cohort studies; design, advantages and limitations; selection of study subjects; matching; confounding; bias and its control; randomized controlled trials; crossover trials; sample size considerations; recruitment strategies; screening programmes; sensitivity, specificity, predictive values and ROC curves. **14 L**

Spatial and Infectious Disease Epidemiology: Geographical representation and disease mapping; spatial interpolation and smoothing methods; estimation and inference in spatial epidemiology; spatial proximity indices; disease clustering; spatial regression; introduction to infectious disease modelling; surveillance systems and outbreak investigation; applications in public health. **12 L**

Modern Statistical Methods in Epidemiology: Measures of association: relative risk, odds ratio and attributable risk; survival analysis in epidemiology; applications of Kaplan–Meier estimator and Cox proportional hazards model; introduction to logistic regression; disease risk prediction models; introduction to statistical genomics, genome-wide association studies (GWAS), biomarkers and precision medicine; case studies in epidemiological and public health research. **10 L**

References

1. Gordis, L. Epidemiology. Elsevier.
2. Rothman, K. J., Greenland, S. and Lash, T. L. Modern Epidemiology. Lippincott Williams & Wilkins.
3. Friis, R. H. and Sellers, T. A. Epidemiology for Public Health Practice. Jones & Bartlett Learning.
4. Bonita, R., Beaglehole, R. and Kjellström, T. Basic Epidemiology. World Health Organization.
5. Kleinbaum, D. G., Kupper, L. L., Nizam, A. and Rosenberg, E. S. Applied Regression Analysis and Other Multivariable Methods. Cengage.
6. Lawson, A. B. Statistical Methods in Spatial Epidemiology. Wiley.
7. Elliott, P., Wakefield, J., Best, N. and Briggs, D. Spatial Epidemiology: Methods and Applications. Oxford University Press.
8. Indrayan, A. Medical Biostatistics. Chapman & Hall/CRC.

OR

2ST-DSE-4.3 Advanced Time Series Analysis

Advanced Univariate Time Series : Time series as a discrete-parameter stochastic process; review of weak stationarity and properties of autocovariance and autocorrelation functions; estimation of mean, autocovariance and autocorrelation functions under large-sample theory; exploratory time series analysis; tests for trend and seasonality; advanced seasonal modelling; Seasonal ARIMA (SARIMA) models; intervention analysis and dynamic regression models; deterministic and stochastic trends; structural breaks and change-point models. **12 L**

State-Space Models and Advanced Forecasting: State-space representation of time series models; observation and state equations; local-level and local-trend models; structural time series models; Kalman filtering and smoothing; forecasting using state-space models; forecast uncertainty and prediction intervals; exponential smoothing in the

state-space framework; forecast evaluation and comparison; rolling-origin evaluation and time-series cross-validation. **12 L**

Multivariate Time Series Analysis: Introduction to multivariate time series; vector autoregressive (VAR) models; estimation and interpretation of VAR models; vector moving average representation; Granger causality; impulse response functions; forecast error variance decomposition; spurious regression; cointegration; error correction models (ECM); vector error correction models (VECM); Johansen's approach to cointegration.

12 L

Spectral, Volatility and Nonlinear Time Series: Spectral analysis; periodogram and spectral density; long-memory processes and fractional differencing; time-varying volatility; ARCH and GARCH models; advanced volatility models including EGARCH and GJR-GARCH; volatility forecasting; nonlinear time series models including threshold autoregressive (TAR) and smooth transition autoregressive (STAR) models; regime-switching and Markov-switching models; applications to economic, financial and environmental time series. **12 L**

References

1. Shumway, R. H. and Stoffer, D. S. Time Series Analysis and Its Applications: With R Examples. Springer.
2. Brockwell, P. J. and Davis, R. A. Introduction to Time Series and Forecasting. Springer.
3. Hamilton, J. D. Time Series Analysis. Princeton University Press.
4. Box, G. E. P., Jenkins, G. M., Reinsel, G. C. and Ljung, G. M. Time Series Analysis: Forecasting and Control. John Wiley & Sons.
5. Lütkepohl, H. New Introduction to Multiple Time Series Analysis. Springer.
6. Tsay, R. S. Analysis of Financial Time Series. John Wiley & Sons.
7. Priestley, M. B. Spectral Analysis and Time Series. Academic Press.
8. Durbin, J. and Koopman, S. J. Time Series Analysis by State Space

Elective Papers: 2ST-DSE-4.4

2ST-DSE-4.4 Advanced Inference

Resampling Techniques: The Jackknife, bias correction, Jackknife estimate of variance, consistency of jackknife (Rupert Miller) and related results. **6L**

The Bootstrap, consistency of Bootstrap (Kesar Singh), discussions on Bootstrap consistency for sample quantile, smooth function of sample mean and in variance estimation. Accuracy of Bootstrap, Bootstrap confidence intervals. **14L**

Deleted Jackknife and m-out-of-n Bootstrap. **4L**

Goodness-of-fit tests: Uniformity, Normality and Exponentiality tests, general purpose goodness-of-fit tests. Goodness-of-fit tests for distributions under censored data. **12L**

Density Estimation: Histogram estimator, Rosenblatt Estimator, Kernel Density Estimator and sample spacings-based estimators. **12L**

References:

1. Shao, J and Tu, D. (1995): The Jack Knife and Bootstrap, Springer.
2. Efron, B. and Tibshirani, R. J. (1993): An Introduction to the Bootstrap, Chapman & Hall.
3. Davison, A. C. and Hinkley, D. V. (1997): Bootstrap Methods and their Application, Cambridge University Press.
4. Hall, P. (1992): The Bootstrap and Edgeworth Expansion, Springer.
5. Chernick, M. R. (2007): Bootstrap Methods: A Guide for Practitioners and Researchers, Wiley.
6. D'Agostino, R. B. and Stephens, M. A. (1986): Goodness-of-Fit Techniques, Marcel Dekker.
7. Huber-Carol, C., Balakrishnan, N., Nikulin, M. S. and Mesbah, M. (2002): Goodness-of-Fit Tests and Model Validity, Birkhäuser.
8. Nikulin, M. S. and Chimitova, E. (2017): Chi-Squared Goodness-of-Fit Tests for Censored Data, Wiley.
9. Silverman, B. W. (1986): Density Estimation for Statistics and Data Analysis, Chapman & Hall.
10. Scott, D. W. (1992): Multivariate Density Estimation: Theory, Practice, and Visualization, Wiley.
11. Wand, M. P. and Jones, M. C. (1995): Kernel Smoothing, Chapman & Hall.
12. Gramacki, A. (2018): Nonparametric Kernel Density Estimation and Its Computational Aspects, Springer.

OR

2ST-DSE-4.4 Bayesian Inference

Historical background and motivation behind Bayesian Inference. 2L

The Bayesian Model Assumptions, Basic examples and advantages of Bayesian Modeling. 2L

Choice of Priors: Objective and subjective priors. Conjugate Priors, natural conjugate family: advantages and existence. PKD theorem (without proof) and related results.

Non-information priors: Laplace Prior and maximum entropy, Jefferey's prior and related examples. Jefferey's prior as a minimizer of KL Divergence. 16L

Bayesian estimation: Asymptotic of the posterior, Bernstein-Von-Mises Theorem and related results, Doob's theorem. 8L

Bayesian Hypothesis Testing 4L

Bayesian Model selection 4L

Bayesian Computation: MCMC, Metropolis Hasting, Gibbs. 6L

Hierarchical Bayes concepts 2L

Non-parametric bayes: Dirichlet process prior. 4L

References:

1. Ghosh, J. K., Delampady, M. and Samanta, T. *An Introduction to Bayesian Analysis: Theory and Methods*. Springer.
2. Gelman, A, Carlin, J, Stern, H, Dunson, D, Vehtari, A and Rubin, D. (2013): Bayesian Data Analysis (3rd Edition), CRC Press.
3. McElreath, R. (2020): Statistical Rethinking (2nd Edition), CRC Press.
4. Müller, P, Quintana, F, Jara, A and Hanson, T. (2015): Bayesian Nonparametric Data Analysis, Springer.
5. Ghosal, S and van der Vaart, A. (2017): Fundamentals of Nonparametric Bayesian Inference, Cambridge University Press.

OR

2ST-DSE-4.4 Industrial Statistics

General Theory and review of control charts for variables and attributes. OC and ARL of control charts; moving average and exponentially weighted moving average charts; CUSUM charts using V-masks and decision intervals. 10L

Group control charts for Multiple-Stream Process and DNOM chart for Short Run Process. Attribute charts for Short Run Process. 4L

Autocorrelated Quality Characteristics: Detection and measure of autocorrelation. Dealing with autocorrelation, Time series model-based approach for monitoring autocorrelated processes. Model-Free approach. 4L

Multivariate Control Chart: Multivariate quality control problem, Chi-square control chart, Estimation of mean vector and dispersion matrix for multivariate normal distribution and Hotelling control chart. Multivariate control chart for individual observations and process variability. 6L

Economic design of control chart: Duncan's Single Assignable Cause Model for Economic Design of Chart. 4L

Engineering Process Control: Determination of feedback adjustment (Integral control) scheme, manual implementation adjustment chart, combining SPC and EPC. 4L

Continuous Sampling Plans: Dodge type and Wald-Wolfowitz type and their properties. Mil. Std. Plans. 5L

Process Capability Indices: PCI for non-normal distributions. 5L

Online Quality Control (Taguchi Methods): Loss function and quality level, derivation of the loss function, loss function and inspection. Online quality control for attributes. 6L

References:

1. D.C. Montgomery (2019): Introduction to Statistical Quality Control. Wiley.
2. Wetherill, G.B. (1977): Sampling Inspection and Quality control, Halsted Press.
3. Wetherill, G.B. Brown, D.W.: Statistical Process Control Theory and Practice, Chapman & Hall.

OR

2ST-DSE-4.4 Advanced Operations Research

Sensitivity analysis in linear programming problems. 4L

Nonlinear programming: graphical method, classical optimization technique, Kuhn-Tucker theorem, Wolfe's algorithm in quadratic programming. 6L

Dynamic programming, Bellman's principle of optimality, general formulation, applications. 6L

Inventory problems, deterministic model, multiple item static model with storage limitation, continuous review model, ABC analysis. 6L

Stochastic programming, chance-constrained programming under normality. 5L

Integer programming, branch and bound and cutting plane method. 5L

Replacement problems, replacement of items that depreciate, block and age replacement policies, staffing problem. 5L

Goal programming. 5L

Sequencing models, Sequencing n jobs on two machines. 2L

Introduction to networks, determination of floats and critical paths, CPM & PERT. 4L

References:

1. Taha, H.A.: Operations Research: An Introduction, 6th Ed. 1997 Prentice–Hall of India.
2. Goel and Mittal: Operations Research, Sultan Chand.
3. Kanti Swarup, P.K. Gupata & M.M. Singh (1985): Operations Research, Sultan Chand.
4. Philips, D.T., Ravindran, A. and Solberg, J: Operations Research,