**DEPARTMENT OF STATISTICS**
**FACULTY OF MATHEMATICAL SCIENCES**
**UNIVERSITY OF DELHI**
**DELHI-110007**

# Ph.D. COURSE WORK IN STATISTICS

The Ph.D. Programme in Statistics as per the ordinance VI-B related to Doctorate of Philosophy (Ph.D.) w.e.f. Academic Year 2017-18.

## Course Structure

There will be 3 Courses for the Ph.D. Course work. Each student shall undertake one compulsory course on Research Methodology (Course Code: Ph.D. - 01) and two other courses decided by his/her Supervisor.

## Courses (i)-(vi):

| Sl. No. | Course Code | Course Name | Credit |
|---|---|---|---|
| (i) | Ph.D. - 01 | Research Methodology | 4 |
| (ii) | Ph.D. - 02 | Design of Experiments | 4 |
| (iii) | Ph.D. - 03 | Bayesian Inference | 4 |
| (iv) | Ph.D. - 04 | Order Statistics | 4 |
| (v) | Ph.D. - 05 | Bio-Statistics | 4 |
| (vi) | Ph.D. - 06 | Reliability and Life Testing | 4 |
| (vii) | Ph.D. - 07 | Industrial Statistics | 4 |
| (viii) | Ph.D. - 08 | Survey Sampling | 4 |
| (ix) | Ph.D. - 09 | Statistical Inference | 4 |

## Scheme of Evaluation

A student admitted to Ph.D. course work will be evaluated on the basis of written examination in 3 courses and on the internal continual assessment. Each course will be of 100 marks out of which 75 marks for written paper, and 25 marks for internal assessment. The students will be assessed continuously on the basis of their assignments/seminars.

## Ph.D. – 01 Research Methodology

Concept of Research in Statistics-Importance and Need for Research Ethics, Selection of Topic for Research, Review of Literature and its Use in Designing a Research Work-Mode of Literature Survey-Books and Monographs, Journals, Conference Proceedings, Abstracting and Indexing Journals, E-Journals/Books. Thesis Writing – Computer Application in Scientific Research, web-Searching, Scientific Articles-Statistical Data Base. History of Statistics. Statistical Heritage of India.

Scientific Word Processing with LaTeX and MS-Word: Article, Thesis Report and Slides Making-Power Point Features, Slide Preparation. Statistical Programming with R: Simple Manipulations Using Numbers and Vectors-Objects & Their Attributes-Arrays and Matrices-Lists and Data Frames-Grouping, Loops and Conditions-User Defined Functions- Probability Distributions and Statistical Models in R.

Simulation: Concepts and Advantages of Simulation-Event Type Simulation-Random Variable Generation-U(0,1), Exponential, Gamma and Normal Random Variables–Monte Carlo Integration. The MCMC Principle, Algorithms and its Variants, Bootstrap Methods.

Computer Oriented Numerical Methods-Algorithms for Solving Algebraic and Transcendental Equations-Numerical Integration-Matrix operations.

**Suggested Readings:**


1. Anderson, J., Durston, B.H., Pooole, M. (1970). Thesis and Assignment Writing, Wiley Eastern. Ltd., New Delhi.
2. Beveridege, B. (1979). The Art of Scientific Investigation, W.E. Norton & Co., New York.
3. Braun, J., Duncan, W. and Murdock, J. (2008). A First Course in Statistical Programming with R, Cambridge University Press, London.
4. Chambers, J. (2008). Software for Data Analysis: Programming with R, Springer, New York.
5. Crewley, M.J. (2007). The R-.Book, John Wiley, New York.
6. Dalgaard, P. (2008). Introductory Statistics with R, Springer Science, New York.
7. Ghosh, J.K., Mitra, S.K. and Parthasarathy, K. R. (1992). Glilmpses of India's Statistical Heritage, Wiley Eastern Limited, New Delhi.
8. Hald, A. (1998). A History of Mathematical Statistics from 1750 to 1930, John Wiley & Sons, New York.
9. Kantiswarup, S., Gupta P.K. and Man Mohan (2008). Operations Research, Sultan Chand & Sons, New Delhi.
10. Kothari, C.R. and Garg, G. (2014). Research Methodology: Methods and Techniques, 3rd Edn., New Age International Publishers.
11. Lamport, L. (1999). LATEX: A Document Preparation System, Addison, Wesley, 2nd edition, New York.
12. Pannerselvan, R. (2006). Research Methodology, Prentice-Hall of India Pvt., New Delhi.
13. Robert, C.P. and Casella, G. (2004). Monte Carlo Statistical Methods, Springer Science, New York.
14. Venkataraman, M.K. (1998). Numerical Methods in Science and Engineering, The National Publishing Company, Chennai.

## Ph.D. – 02 Design of Experiments

Galois Fields, Quadratic Residues, Hadamard Martices, Plackett Burman Designs and their properties, Orthogonal Arrays and their constructions, Designs for fitting response surfaces, Design criterion involving bias and variance. Mixture Experiments, Constraints on component proportions, Designs for Constrained Mixture Regions, Crossover Designs.

**Suggested Readings:**


1. Bose, M. and Dey, A. (2009). Optimal Crossover Designs. World Scientific.
2. Cornell, John A. (2002). Experiments with Mixtures, John Wiley & Sons.
3. Dey, A. and Mukerjee, R. (1999). Fractional Factorial Plans, John Wiley & Sons.
4. Hedayat, A. S., Sloane, N. J.A. and Stufken, J. (1999). Orthogonal Arrays: Theory and Applications, Springer.
5. Hinkelmann, K. and Kempthorne, O. (2005). Design and Analysis of Experiments, Vol. 2: Advanced Experimental Design, John Wiley & Sons.
6. Lin, D.K. J. and Draper, N.R. (1999). Projection Properties of Plackett and Burman Designs. Technometrics, 34, 423-428.
7. Myers, R. H. and Montgomery, D. C. (2002). Response Surface Methodology: Process and Product Optimization using Designed Experiments, John Wiley & Sons.
8. Raghavarao, D. (1970). Construction and Combinatorial Problems in Design of Experiments, John Wiley & Sons.


## Ph.D. – 03 Bayesian Inference

Some simple consequences of Axioms of probability, Bayes Theorem. Conjugate analysis for count data, waiting times, Normal likelihood, multivariate normal distribution, normal linear regression model. Behrens-Fisher Controversy.

Informative, non-informative, hybrid and nonparametric priors. Loss functions. Bayes factor, Information theoretic measures for model selection, sensitivity and robust analysis. Bayes point estimation: one parameter, Bayes decisions between k simple hypothesis and between two composite hypothesis. Lindley's method.

Hierarchial models - Poisson-gamma, Gaussian, linear mixed, nonlinear mixed.

Empirical Bayes : asymptotic optimality and robustness with respect to prior distribution.

Computational Bayesian Statistics.

**Suggested Readings**


1. Congdon, P. (2003). Applied Bayesian Modelling. Wiley.
2. Congdon, P. (2010). Applied Bayesian Hierarchical Methods. Chapman & Hall.
3. Thompson, J. (2014). Bayesian analysis with STATA. (2014). State Press.

4. Albert, J. (2007). Bayesian Computation with R. Springer.
5. Gelman, A. , Carlin, J. , Stern, H. , Vehtari, D.D.A. and Rubin, D. (2004). Bayesian Data Analysis. Chapman & Hall, 2nd ed.
6. Upadyaya, S.K. , Singh, U. and Dey, D.K. eds. (2007). Bayesian Statistics and its applications. Anamaya, Delhi.
7. Kruschke, J.K. (2015). Doing Bayesian Data Analysis. Elsevier AP.
8. Koch, K. R. (2010). Introduction to Bayesian Statistics, 2nd ed. Springer.
9. French, S. and Smith, J. Q. eds. (1997) The Practice of Bayesian analysis (1997). Arnold Publisher.

## Ph.D. – 04 Order Statistics

Basic distribution theory, conditional distributions, order statistics as a Markov Chain, order statistics for independent non-identically distributed variates; Discrete order statistics, Joint probability mass function, Dependence structure; Expected values and moments; Order statistics from some specific distributions; Recurrence relations, bounds and approximations for moments of order statistics; Concomitants of order statistics; Order statistics in statistical inference; Order statistics from a sample containing a single outlier; Asymptotic theory; Record values; Generalized order statistics.

**Suggested Readings:**

1. Ahsanullah, M., Nevzorov, V.B. and Shakil, M. (2013). An Introduction to Order Statistics. Atlantis Studies in Probability and Statistics, Vol. 3, Atlantis Press.
2. Arnold, B.C. and Balakrishnan, N. (1989). Relations, Bounds and Approximations for Order Statistics. Lecture Notes in Statistics, Vol.53, Springer-Verlag.
3. Arnold, B.C. Balakrishnan, N. and Nagaraja, H.N. (1992). A first course in Order Statistics, John Wiley.
4. Arnold, B.C., Balakrishnan, N. and Nagaraja, H.N. (1998). Records, John Wiley.
5. David, H.A. and Nagaraja, H.N. (2003). Order Statistics, Third Edition, John Wiley.
6. Galambos, J. (1987). The Asymptotic Theory of Extreme Order Statistics, Second Edition, Krieger, F.L.
7. Kamps, U. (1995). A Concept of Generalized Order Statistics, B.G. Teubner Stuttgart.

## Ph.D. – 05 Bio-Statistics

Nelson –Aalen estimator of cumulative hazard function along with its variance, Its applications in survival analysis, Markov illness death model and epidemic model, Graphical methods for survival distribution fitting and goodness of fit tests, Parametric and non-parametric methods of comparing survival distributions, Mantel -Haenszel test, Estimation of mean residual lifetime with applications, Likelihood construction for

censored and truncated data, Cox PH model along with its likelihood construction, Construction of clinical life table, Carrier Borne epidemic model. Competing risk theory with censoring.

**Suggested Readings:**


1. Biswas, Suddhendu (1995). Applied Stochastic Processes, New Central Book Agency.
2. Collett, David (2015). Modelling Survival Data in Medical Research, CRC press.
3. Klein, John P., and Moeschberger, Melvin L. (2005). Survival Analysis: Techniques for Censored and Truncated Data, Springer Science & Business Media.
4. Kleinbaum, David G., and Mitchel Klein (2006). Survival Analysis: A Self-learning Text, Springer Science & Business Media.
5. Lee, Elisa T., and Wang, John W. (2003). Statistical Methods for Survival Data Analysis, John Wiley & Sons.
6. Pintilie, Melania (2006). Competing Risks: A Practical Perspective, John Wiley & Sons.


## Ph.D. – 06 Reliability and Life Testing

Reliability, hazard-rate and mean time to failure and their inter-relationships. Statistical failure models: exponential. Gamma, Weibull, Pareto, normal, lognormal and related distributions. Parametric and Reliability estimation under regression.

Censoring under Type-I, Type-II, and Progressive schemes with applications in life testing. Estimation of parameters of reliability function with complete and censored samples for some selected distributions. Tests of hypotheses and confidence intervals for the reliability function of exponential, gamma,Weibull, normal and lognormal distributions.

Life-time distributions in Reliability analysis, Reliability concepts and measures, Reliability functions, hazard rate functions, Reliability of Series Parallel k-out of- n- systems, coherent systems, standby components, Repairable systems with and without redundancy, preventive maintenance policy. Classes of life distributions: IFR, IFRA, NBU, NBUE and their duals.

**Suggested Readings:**


1. Bain, L.J. and Engelhardt, M. (1991). Statistical Analysis of Reliability and Life- Testing Models, Marcel Dekker Inc., U.S.A.

2. Cohen, A.C. and Whitten, B.J. (1988). Parameter estimation in Reliability and Life Span Models, Marcel Dekker Inc., U.S.A.

3. Gerstbakh, I.B. (1989). Statistical Reliability Theory, Marcel Dekker Inc., New York.

4. Hoyland, A. and Rausand, M. (1994). System Reliability Theory: Models and Statistical Theory. Marcel Dekker Inc., New York.

5. Kalbfleisch, J.D. and Prentice, R.L. (1980). The Statistical Analysis of Failure Time Data, John Wiley and Sons, New York.

6. Lawless, J.F. (1982). Statistical Models and Methods for Lifetime Data, John Wiley and Sons Jnc.,.U.S.A.

7. Mann, N.R., Schafer, R.E. and Singpurwala, N.D. (1974). Methods for Statistical Analysis

of Reliability and Life Data, John Wiley, New York.

8. Martz, H.F. and Wailer, R.A. (1982). Bayesian Reliability Analysis, John Wiley and Sons, Inc., New York.

9. Sinha, S.K. (1986). Reliability and Life-Testing, Wiley Eastern Ltd., New Delhi.

10. Zacks, S. (1992). Introduction to Reliability Analysis, Springer-Verlag, U.S.A.

11. Barlow, R., Prochan, F. (1985). Statistical Theory of Life Testing. Holt, Rinehart and Winston, New York.

12. Lai, C. D. and Xie, M. (2006). Stochastic Aging and Dependence for Reliability, Springer-Verlag, U.S.A.

13. Deshpande, J.V. and Puohit, S. (2003). Life-Time Data: Statistical Models and Methods Series on Quality, World Scientific Publishing.

14. Lee, E.T. and Wang, J.W. (2003). Statistical methods for Survival data analysis. John Wiley and Sons, Inc., New York.

15. Meeker, W.Q. and Escobar, L.A. and Pascual, F.G. (2022). Statistical methods for Reliability data. John Wiley and Sons, Inc., New York.

## Ph.D. – 07 Industrial Statistics

**Introduction**

Causes of Variation, Warning limits, Average run length, Control Charts for Variables and Attributes, Standardized Control Charts, Statistical process control with auto-correlated process data, Control chart for demerits per unit, Control charts for Individual Units, Cumulative Sum Control Charts, Moving average and Exponentially Weighted Moving Average Control Charts, Multivariate control charts, Process Capability Indices for normal and non-normal Distributions.

**Conceptual notions and applications**

Producer's risk, Consumer's risk, Acceptance sampling plan, Single and double sampling plans by attributes, OC, ASN (and ATI), LTPD, AOQ and AOQL curves, Single sampling plan for variables, Lot-by-Lot Attribute Sampling Plans, Acceptance sampling plans. Continuous sampling plans: Bayesian, Multiple, Sequential.

**Implementation in industry through data**

Regression models, Residual Analysis, Transformation of response variable- Box-cox method, Nonlinear regression models, Estimation of parametric functions and related hypotheses testing, Auto-covariance and Autocorrelation functions and their properties, Stationary processes: Moving average (MA) process, Auto-regressive (AR) process, ARMA, ARIMA and SARIMA models.

**Suggested Readings:**

1. Montgomery, D.C. (2009): Introduction to Statistical Quality Control, Wiley.
2. Wetherill, G.B. and Brown, D.W. (1991): Statistical Process Control: Theory and Practice, Chapman & Hall.

3. Wetherill, G.B. (1977): Sampling Inspection and Quality control, Halsteed Press.
4. Duncan, A.J. (1974): Quality Control and Industrial Statistics, IV Edision, Taraporewala and Sons.
5. Ott, E. R. (1977): Process Quality Control (McGraw Hill)
6. Lawless, J.F. (1982): Statistical model and Methods of Life time data, John Willey.
7. Georg, E.P., Gwilym M. Jenkins and Gregory C. Reinsel (1994): Time series Analysis forecasting and Control, Prentice-Hall International Inc.
8. Brockwell, P.J. and Davis, R.A. (2016): Introduction to Time Series and Forecasting, Springer.

## Ph.D. – 08 Survey Sampling

**Review of Methods and Properties**

Fixed population and super-population approaches; Review of various sampling methods with properties; Post and deep stratification; PPSWR/WOR methods, Des Raj and Murthy estimators; Horvitz Thompson Estimator of finite population, IPPS schemes of sampling due to Midzuno-Sen, Rao-Hartley-Cochran and Samphord, Controlled Sampling; randomized response techniques and its various applications.

**Resampling and Situation-specific Techniques**

Resampling Techniques for variance estimation; Ratio Estimation in reference to Jackknife and bootstraps; Relationship between the jackknife and the bootstrap; Successive sampling for two occasion for estimation of population mean/ratio; situation-specific Sampling Schemes: Estimation of mean and variance using ranked set sampling (RSS); RSS in parametric and non-parametric estimation; various versions of RSS; Imperfect ranking; Adaptive Cluster Sampling (ACS); ACS based on order statistics

**Small Area Estimation (SAE) Techniques and Non sampling erros**

Design and model based SAE techniques; Direct and Indirect Estimators; Fay-Herriot Model, EBLUP Estimator; Applications in various sectors.

Non-sampling errors, imputation methods for non response, and analysis of survey data. Data integration by combining probability samples with non-probability samples.

**Suggested Readings:**

1. Chaudhuri, A. and Mukerjee, R. (1988): Randomized Response: Theory and Techniques, New York: Marcel Dekker Inc.
2. Cochran, W.G. (1977): Sampling Techniques. Wiley.
3. Sukhatme, P.V., Sukhatme, B.V. and Ashok A.: Sampling Theory of Surveys with Applications, Indian Society of Agricultural Statistics, New Delhi.
4. Latpate, R., Kshirsagar, Gupta, V.K. and Chandra, G. (2020). Advanced Sampling Methods. Springer
5. Mukhopadhay, P. (2008). Theory and Methods of Survey Sampling, Prentice Hall.
6. Murthy, M. N. (1977): Sampling Theory & Methods, Statistical Publishing Society, Calcutta.
7. Rao, J.N.K. and Molina, I. (2015). Small area estimation, 2nd Edition, Wiley
8. Thompson, S.K. (1996). Adaptive Sampling. John Wiley and Sons
9. Wu and Thompson (2019). Sampling theory and practice. Springer

## Ph.D. – 09 Statistical Inference

**Introduction of Concepts**

Random sample and generation of random sample, Sampling distribution -Z, t, Chi-square, F, Order Statistics, Convergence concepts, Weak and strong laws of large numbers, Central limit theorem, Sufficiency principle, Likelihood principle, Basu's Theorem. Invariance and maximal invariant statistic.

**Estimation for some selected new distributions:**

Methods of finding estimators: Method of moments, Maximum likelihood estimators, Methods of evaluating estimators-best unbiased estimator, sufficiency and completeness, Rao-Cramer inequality, Fisher Information, Rao-Blackwell and Lehmann-Scheffe Theorems, Loss and risk functions, admissibility, minimax and Bayes estimators.

Interval estimation: Pivotal quantities, Credible and highest posterior density interval, Coverage probability and Interval length, Expectation-Maximization (EM) algorithm, Bootstrap method: construction of bootstrap confidence intervals.

**Testing for some selected new distributions:**

Neyman-Pearson theory, Most Powerful (MP)Test, UMP Test, Likelihood ratio tests, Wald's Sequential Probability ratio Test (SPRT), Invariant tests. Parametric hypothesis testing methods, One-way and two-way ANOVA, Regression-least square method.

**Suggested Readings:**


1. Casella, G. and Berger, R.L. (2002) Statistical Inference, Duxbury, USA.
2. Rao, C.R. (1973) Linear Statistical Inference and Its Applications, John Wiley.
3. Kale, B.K. (1999) A First Course on Parametric Inference, Narosa Publishing House, New Delhi.
4. Lehmann, E.L. and Casella, G. (1998) Theory of Point Estimation, Springer.
5. Lehmann, E.L. and Romano, J.P. (2005) Testing Statistical Hypotheses, Springer.
6. Keener R. W. (2010) Theoretical Statistics: Topics for a Core Course, Springer.