BANASTHALI VIDYAPITH

Master of Philosophy (Mathematical Science)

Curriculum Structure

First Semester Examination, December, 2019

Second Semester Examination, April/May, 2020

BANASTHALI VIDYAPITH
P.O. BANASTHALI VIDYAPITH
(Rajasthan)-304022

July, 2019

145

No. F. 9-6/81-U.3

Government of India
Ministry of Education and Culture
(Department of Education)

New Delhi, the 25th October, 1983

N O T I F I C A T I O N

In exercise of the powers conferred by Section 3 of the University Grants Commission Act, 1956 (3 of 1956) the Central Government, on the advice of the Commission, hereby declare that Banasthali Vidyapith, P. O. Banasthali Vidyapith, (Rajasthan) shall be deemed to be a University for the purpose of the aforesaid Act.

Sd/-
(M. R. Kolhatkar)
Joint Secretary of the Government of India

N O T I C E

Changes in Bye-laws/Syllabi and Books may from time to time be made by amendment or remaking, and a Candidate shall, except in so far as the Vidyapith determines otherwise, comply with any change that applies to years she has not completed at the time of change.

CONTENTS

Progamme Educational Objectives

Banasthali's education ideology is to nurture women leaders in all walks of life with strong value base. Mathematical Sciences is the most important discipline in today's world which has applications in engineering, business, finance, computing, data science, health sciences and environmental sciences. The educational objective of the M.Phil. Mathematical Sciences programme is to motivate students to learn advanced and emerging research areas in various fields of mathematics and statistics in order to prepare students for professional careers in mathematical sciences and related fields.

The aim of the programme is to equip students with mathematical and statistical knowledge to develop research level thinking. It emphasizes on research skills and to develop the ability to critically analyze the undertaken research area to produce a piece of written work as dissertation.

The main objectives of the M.Phil. (Mathematical Sciences) programme are:

- To develop the ability to define, design and deliver a significant piece of research work that is clear and coherent.
- To impart necessary skills and knowledge of deeper understanding of chosen research area.
- To use mathematical and statistical techniques to solve well-defined real-world problems and understand the limitations.
- To develop communication and technical writing skills which enables students to present mathematical and statistical ideas clearly in oral and written forms using appropriate technical terms and deliver data analysis results.
- To nurture skills in effective multidisciplinary teamwork and adherence to principles of professional accountability and ethics.

Programme Outcomes

- **PO1: Knowledge Domain:** Demonstrate an understanding of research in mathematical sciences and ability to define, design and deliver a significance piece of research work that is clear and coherent.
- **PO2: Problem Analysis:** Analyze and solve the well-defined research problems in mathematics, statistics and operations research. Utilize the principles of scientific enquiry, thinking analytically, clearly and critically, while solving problems and making decision. Find, analyze, evaluate and apply information systematically and shall make defensible decisions.
- **PO3: Presentation and Interpretation of Data:** Demonstrate the ability to manipulate and visualize data and to compute standard statistical summaries.
- **PO4: Modern Tool Usage:** Learn, select and apply appropriate methods and procedures, resources and computing tools such as Excel, MATLAB, MATHEMATICA, SPSS, R etc. with an understanding of the limitations.
- **PO5: Technical Skills:** Understand tools of modeling, simulation and data analysis to bear on real-world problems, producing solutions with the power to predict and explain complex phenomena.
- **PO6: Ethics:** Analyze relevant academic, professional and research ethical problems and commit to professional ethics and responsibilities with applicable norms of the data analysis and research practices.
- **PO7: Communication:** Effectively communicate about their field of expertise on their activities, with their peer and society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations.
- **PO8: Project Management:** Apply knowledge and understanding of principles of mathematics and statistics effectively as an individual, and as a member or leader in diverse teams to manage projects in multidisciplinary environment.

- **PO9:** **Research Proposal:** Define, design and deliver a significant piece of research work that is clear and concise. Demonstrate the necessary skills and knowledge of deeper understanding of their chosen research area. Understand the philosophy of research in mathematical sciences and appreciate the value of its development.

- **PO10:** **Life-Long learning:** Demonstrate the ability to read and learn mathematical and statistical tools on their own that encourage independent exploration in the specific area of mathematics, statistics, operations research and theoretical computer science. Continue to acquire mathematical and statistical knowledge and skills appropriate to professional activities in the context of technological change.

Curriculum Structure

Master of Philosophy (Mathematical Sciences - Mathematics/ Statistics/Operations Research)

Semester - I

Course	Code	Course Name	L	T	P	C*
MATH	602	Advanced Analysis	4	0	0	4
MATH	626	Research Methodology	4	0	0	4
MATH	628P	Term Paper	0	0	24	12
		Discipline Elective	4	0	0	4
		Reading Elective - I	0	0	0	2
		Semester Total:	**12**	**0**	**24**	**26**

Semester - II

Course	Code	Course Name	L	T	P	C*
MATH	625D	Dissertation	0	0	36	18
MATH	627S	Seminar	0	0	8	4
		Reading Elective - II	0	0	0	2
		Reading Elective - III	0	0	0	2
		Semester Total:	**0**	**0**	**44**	**26**

List of Discipline Elective

Course	Code	Course Name	L	T	P	C*
MATH	504	Analytic and Algebraic Number Theory	4	0	0	4
MATH	507	Financial Mathematics	4	0	0	4
MATH	527	Tensor Analysis and Geometry of Manifolds	4	0	0	4
MATH	601	Advance Graph Theory	4	0	0	4
MATH	614	Finsler Geometry	4	0	0	4
MATH	619	Mathematical Cryptography	4	0	0	4
STAT	504	Clinical Trials	4	0	0	4
STAT	505	Decision Theory	4	0	0	4
STAT	508	Distribution Theory	4	0	0	4
STAT	522	Econometric Models	4	0	0	4
STAT	511	Non Parametric Inference and Sequential Analysis	4	0	0	4
STAT	513	Regression Analysis	4	0	0	4
STAT	603	Bayesian Inference	4	0	0	4
STAT	609	Population Sciences	4	0	0	4
STAT	613	Time Series Modeling	4	0	0	4
STAT	524	Reliability and Renewal Theory	4	0	0	4
MATH	543	Fuzzy Logic and Belief Theory	4	0	0	4
MATH	546	Inventory Theory	4	0	0	4
MATH	555	Queueing Theory	4	0	0	4
MATH	539	Fields and Galois Theory	4	0	0	4
MATH	534	Coding Theory	4	0	0	4
MATH	540	Fixed Point Theory	4	0	0	4
MATH	545	Introduction to Dynamical System	4	0	0	4
MATH	533	Bio Mathematics	4	0	0	4
MATH	535	Combinatorial Optimization	4	0	0	4
MATH	559	Transportation System Analysis	4	0	0	4
STAT	527	Stochastic Models	4	0	0	4
STAT	521	Demography	4	0	0	4

List of Reading Elective						
Course	**Code**	**Course Name**	**L**	**T**	**P**	**C***
MATH	603R	Advanced Cryptography	0	0	0	2
MATH	604R	Advanced Queueing Models	0	0	0	2
MATH	605R	Algebraic Aspects of Cryptography	0	0	0	2
MATH	606R	Algebraic Geometry	0	0	0	2
MATH	609R	Decision and Game Theory	0	0	0	2
MATH	612R	Finite Element Methods	0	0	0	2
MATH	613R	Finite Field Theory	0	0	0	2
MATH	616R	Intelligent Transport System	0	0	0	2
MATH	617R	Inventory and Production Management	0	0	0	2
MATH	618R	Marketing Management	0	0	0	2
MATH	621R	Numerical Solutions of Partial Differential Equations	0	0	0	2
MATH	622R	Operator Theory	0	0	0	2
MATH	624R	Special Functions	0	0	0	2
STAT	602R	Advanced Reliability Theory	0	0	0	2
STAT	604R	Biostatistics	0	0	0	2
STAT	608R	Generalised Linear Models	0	0	0	2
STAT	610R	Statistical Computing	0	0	0	2
STAT	611R	Supply Chain Management	0	0	0	2
STAT	612R	Survival Analysis	0	0	0	2

*** L - Lecture hrs/week; T - Tutorial hrs/week; P-Project/Practical/Lab/All other non-classroom academic activities, etc. hrs/week; C - Credit Points of the Course**

Evaluation Scheme and Grading System

Continuous Assessment					End - Semester Assessment (ESA)	Grand Total (Max. Marks)
I	II	III	IV	Total (CA)		
10	10	10	10	40	60	100

In all theory, laboratory and other non classroom activities (project, dissertation, seminar, etc.), the Continuous and End-semester assessment will be of 40 and 60 marks respectively. However, for Reading Elective, only End semester exam of 100 marks will be held. Wherever desired, the detailed breakup of continuous assessment marks (40), for project, practical, dissertation, seminar, etc shall be announced by respective departments in respective student handouts.

Based on the cumulative performance in the continuous and end-semester assessments, the grade obtained by the student in each course shall be awarded. The classification of grades is as under:

Letter Grade	Grade Point	Narration
O	10	Outstanding
A+	9	Excellent
A	8	Very Good
B+	7	Good
B	6	Above Average
C+	5	Average
C	4	Below Average
D	3	Marginal
E	2	Exposed
NC	0	Not Cleared

Based on the obtained grades, the Semester Grade Point Average shall be computed as under:

$$SGPA = \frac{CC_1 * GP_1 + CC_2 * GP_2 + CC_3 * GP_3 + ---- + CC_n * GP_n}{CC_1 + CC_2 + CC_3 + ---- + CC_n} = \frac{\sum_{i=1}^{n} CC_i * GP_i}{\sum_{i=1}^{n} CC_i}$$

Where n is the number of courses (with letter grading) registered in the semester, CC_i are the course credits attached to the i^{th} course with letter

grading and GP_i is the letter grade point obtained in the i^{th} course. The courses which are given Non-Letter Grades are not considered in the calculation of SGPA.

The Cumulative Grade Point Average (CGPA) at the end of each semester shall be computed as under:

$$CGPA = \frac{CC_1 * GP_1 + CC_2 * GP_2 + CC_3 * GP_3 + ---- + CC_n * GP_n}{CC_1 + CC_2 + CC_3 + ---- + CC_n} = \frac{\sum_{i=1}^{n} CC_i * GP_i}{\sum_{i=1}^{n} CC_i}$$

Where n is the number of all the courses (with letter grading) that a student has taken up to the previous semester.

Student shall be required to maintain a minimum of 4.00 CGPA at the end of each semester. If a student's CGPA remains below 4.00 in two consecutive semesters, then the student will be placed under probation and the case will be referred to Academic Performance Review Committee (APRC) which will decide the course load of the student for successive semester till the student comes out of the probationary clause.

To clear a course of a degree program, a student should obtain letter grade C and above. However, D/E grade in two/one of the courses throughout the UG/PG degree program respectively shall be deemed to have cleared the respective course(s). The excess of two/one D/E course(s) in UG/PG degree program shall become the backlog course(s) and the student will be required to repeat and clear them in successive semester(s) by obtaining grade C or above.

After successfully clearing all the courses of the degree program, the student shall be awarded division as per following table.

Division	CGPA
Distinction	7.50 and above
First Division	6.00 to 7.49
Second Division	5.00 to 5.99
Pass	4.00 to 4.99

CGPA to % Conversion Formula: % of Marks Obtained = CGPA * 10

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M.Phil. Programme in Mathematical Sciences
Mathematics/Operations Research/Statistics

Eligibility: M.A./M.Sc. in Mathematical Sciences/ Mathematics/ Statistics/ Operations Research/Applied Mathematics from the Vidyapith or a recognized examination equivalent thereto with aggregate equal to or more than 55% marks.

Admission: Based on Entrance exam.

Course structure:

1. A two-semester course, with two core courses, one discipline elective, one reading elective and term paper in first semester, and two reading electives and seminar in second semester, and
2. Dissertation: Student must carry out a Dissertation (submitted in the end of second semester) under the supervision of faculty.

Dissertation

1. The students have to decide on which area they want to do their Dissertation work. In the first week of September the selected topic need to be defended before the faculty members. The students will present a report giving area, list of reviewed journals, articles and referred books.
2. The student has to submit a synopsis of her Dissertation after Diwali breaks. The internal examiners committee will be appointed. The synopsis must also bear the certificate by the supervisor/guide. Student will defend the synopsis in front of internal examiners committee.
3. A mid-term presentation of research work done has to be given and to be defended in front of internal examiners committee in the month of February.
4. At the end of the second semester final report is to be submitted and a presentation and viva-voce will be held.
5. Dissertation will be sent for external evaluation. The list of three external examiners will be made available by the supervisor in consent with the Head of the department.

Scheme of Examination

1. The course of study for M.Phil. Examination shall extend over a period of one year divided into two semesters. First semester contains coursework with an examination at the end of semester and second semester contains submission of dissertation with a viva voice.

2. The Examination shall be conducted by means of Continuous assessment/Written Papers/ Practical/Dissertation/Project Report.

Students would not be allowed to take the course as an elective, which she had already done in M.A./M. Sc.

Core Papers

MATH 602 Advanced Analysis

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Tell what is Normed spaces
- Explain when Normed space become Banach space
- Define the Hilbert spaces
- Define multi linear mappings
- Check whether the function is bounded or not?
- Understand directional derivative.
- Explain the difference between partial derivative and directional derivative
- Tell about the fixed point
- Tell about the Lipschitz's constant and conditions
- Relate the analysis and differential equation

Section A

Normed linear spaces & Banach spaces, bounded linear transformations, multi linear mappings, inner product spaces, Hilbert spaces, orthonormal systems, the space of bounded functions, the space of continues functions, Stone-Weierstrass approximates theorem, equi continuous sets.

Section B

The derivative, directional derivative, partial derivative, mean value theorem, continuously differentiable maps, Higher derivatives, Taylor's Theorem, existence theorem on differentiable maps, Fixed point theorem, step functions, regulated functions.

Section C

Spectral theory in finite dimensional normed spaces, Spectral properties of bounded linear operators, further properties of Resolvent & Spectral, Banach Algebras,Compact linear operators and their properties, Spectral properties of compact linear operation.

Suggested Text/ Reference Books:

1. Dieudonne, J. (1969). *Treatise on Analysis Volume – I: Foundations of Modern Analysis*. Academic Press New York.
2. Cartan, H. (1983). *Differential Calculus.* London: Kershaw Publishing Company Pvt. Ltd.
3. Hewitt, E. & Stromberg, K. (1978). *Real and Abstract Analysis*: A modern treatment of the theory of functions of a real variable, New Delhi, India: Narosa Publishing House.
4. Yosida, K. (1978), *Functional Analysis.* Berlin: Springer Verlag.
5. Kreyszig, E. (1989), *Introductory Functional Analysis with Applications*. John Wiley & Sons, New York.
6. Bachman, G., & Naric, L. (2000). *Functional Analysis.* Dover Publication.

Suggested E-learning material:

1. Normed space Banach space and Hilbert spaces and its properties; Platform:https://nptel.ac.in/courses/11110503/

MATH 626 Research Methodology

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the philosophy of research in mathematics and statistics.

- Develop and understand various mathematical concepts and modeling techniques required for successful application of mathematics.
- Understand and solve multidisciplinary application problems. use appropriate technology to solve problems applying techniques of mathematics.

Section A

Science and Research, Meaning and objectives of research, motivation in research, research approaches, time and energy management, Verification Vs. Falsification, Objectivity: Facts, theory and concepts, Basic Steps for doing Research, Formulation of Research Problem, Reviewing a paper, Significance of literature review, Writing scientific report, structure and components of research report, revision, writing project proposal, writing a Research Paper, Citation counting and Impact factor, Science citation index (SCI)/ Science citation index Expended (SCI-E), H-index,

Section B

Mathematical modelling: Need, techniques, classification, characteristics of mathematical models, limitations of mathematical modelling.

Mathematical modelling through ordinary differential equations of first order and system of ordinary differential equations of first order: Linear growth and decay models, Nonlinear growth and decay models. Mathematical modelling through ordinary differential equations of second order: Planetary motion, circular motions.

Section C

Mathematical modelling through difference equations: Basic theory of linear difference equations with constants coefficients, Models used in Economics, Finance, Population Dynamics, Genetics. Mathematical modelling through graphs: Modelling by directed graphs, signed graphs and weighted digraphs.

Suggested Book:

1. Kothari, C. R. (2013). *Research methodology: Methods and techniques*. (2nd Ed.). New Delhi: New Age International Publishers.
2. Kapur, J.N.(1990). *Mathematical Modelling*. Wiley Eastern Ltd.
3. Caldwell, J., & Ram, Y.M. (1999). *Mathematical Modelling: Concepts and Case Studies*. Springer.
4. Samarskii, A. A., & Mikhailov, A. P. (2002). *Principles of Mathematical Modelling, Ideas, Methods, Examples*. Taylor and Francis.
5. Oliver, P. (2004). Writing Your Thesis,New Delhi:Vistaar Publications, 2004.
6. Day, R. A., (1992) How To Write and Publish a Scientific Paper, Cambridge University Press, London.

Discipline Electives

MATH 504 Analytic and Algebraic Number Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Demonstrate the knowledge of arithmetic functions and their property.
- Know the prime number theorem and its analytic proof.
- Understand basic concepts of algebraic number theory such as conjugates, discriminants, algebraic integers, integral basis, norms and traces.
- Understand prime factorization of ideal and unique factorization.
- Know some important theorem in algebraic number theory.

Section A

Arithmetic functions, Dirichlet product of arithmetical functions, Multiplicative functions, Bell series of an arithmetical function, The Selberg identity, Euler's summation formula, Chebyshev's functions, equivalent forms of the prime number theorem, Dirichlet Series, Euler Products, Analytic Proof of the Prime Number Theorem

Section B

Algebraic numbers, conjugates and discriminants,algebraic integers, integral basis, norms and traces, ring of integers, quadratic fields, cyclotomic fields, trivial factorization, factorization into irreducibles, Non-unique factorization, consequences of unique factorization, Ramanujan-Nagell Theorem

Section C

Prime factorization of ideal, norm of an ideal, non-unique factorization in cyclotomic fields, lattices, quotient torus, Minkowski's theorem, two square theorem, four square theorem, class-group, finiteness of the class-group,Unique factorization of elements in an extension ring.

Suggested Text Books:

1. Stewart, I., & Tall, D. O. (2000). *Algebraic number theory*. London: CRC Press.
2. Apostol, T. M. (1998). *Introduction to analytic number theory*. New York: Springer.

Suggested Reference Books:

1. Ireland, K. F., & Rosen, M. I. (2004). *A classical introduction to modern number theory*. (2nd Ed.). New Delhi: Springer India.
2. Lang, S. (1994). *Algebraic number theory*. New York: Springer-Verlag.
3. Marcus, D. A., & Springer Nature. (2018). *Number fields*. Cham: Springer.

MATH 507 Financial Mathematics

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand financial analysis and planning.
- Know the cost of capital, capital structure and dividend policies.
- Apply technique of Goal Programming to profit planning and financial budgeting.
- Make financing decision onproblem of determining optimal capital structure
- Understand the concept of leasing, debt management, analysis of commitment of funds and risk of cash insolvency.

Section A

Role of Financial Management. Financial Analysis and planning. Working Capital Management. Cost of Capital, Capital Structure and Dividend Policies, Short term and Long term Financial Planning.

Section B

Analytical Approach to Finance. Technique of Goal Programming and its Application to Profit Planning and Financial Budgeting. Capital Expenditure Decision under Risk.

Section C

Financing Decision: Problem of determining optimal capital structure, Leasing, Debt Management, Analysis of commitment of funds and risk of cash insolvency; Receivables and Inventory Management Approaches, Simulation Approach to Working Capital Management.

Suggested Books:

1. Van, H. J. C., &Wachowicz, J. M. (2010). *Fundamentals of financial management*. New Delhi: PHI Learning.
2. Bringham, E. F., Ehrhardt, M. C., &Gapenski, L. C. (1999). *Financial management: Theory and practice : Test Bank*. (9th Ed.). Forth Worth: Dryden Press.
3. Khan, M. Y., & Jain, P. K. (2007). *Financial management*. New Delhi: Tata McGraw-Hill.
4. Clark, J. J., Hindelang, T. J., & Pritchard, R. E. (1989). *Capital budgeting: Planning and control of capital expenditures*. (3rd Ed.). London: Prentice-Hall International.
5. Donaldson, G. (2000). *Corporate Debt Capacity: A Study of Corporate Debt Policy and the Determination of Corporate Debt Capacity (Business Classics)*. Kenilworth: Brand Development Network International, Inc.
6. Fogler, H. R., & Ganapathy, S. (1982). *Financial econometrics for researchers in finance and accounting*. Englewood Cliffs, N.J: Prentice-Hall.
7. Levy, H., &Sarnat, M. (1999). *Capital investment and financial decisions*. (5th Ed.). New York: Prentice Hall.
8. Mao, J. C. T. (1969). *Quantitative analysis of financial decisions*. New York: Macmillan.
9. Van, H. J. C. (2008). *Financial management and policy*. New Delhi: PHI Learning.
10. Yadav, R. A. (1986). *Financial ratios and the prediction of corporate failure*. New Delhi: Concept Pub. Co.

MATH 527 Tensor Analysis and Geometry of Manifolds

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Discuss different kinds of surfaces, connection and covariant derivatives.
- Understand the concepts of manifold and illustrate some examples of manifolds.
- Understand the Ricci identity and enable to use it in proving different theorems.
- Define and illustrate some examples of Lie group.

Section A

Topological manifolds, Differentiable manifolds (Definition and examples), Differentiable Structures defined on sets, Smooth maps on a manifold, Smooth map between two manifolds, Smooth curves, Tangent vectors, Tangent space, Tangent bundle, Differentials of Smooth maps, Immersion and Embedding (Definition and examples only), Vector fields and Lie bracket.

Section B

Tensor Algebra : Tensor product of vector spaces, Contravariant and covariant vectors, Contravariant, covariant and mixed tensors of second order, Tensors of type (r, s), Tensor product of tensors, Contraction, Symmetric and skew-symmetric tensors, Covariant differentiation of Tensors. Differential forms, Exterior derivative, Lie derivatives, Lie groups (Definition & Examples), Cartan's Structural Equation.

Section C

Linear connections: Affine connections, covariant derivative of a Connection, Torsion and Curvature tensors, Difference tensor of two connections, Riemannian metric, Riemannian connection, Riemann

Curvature tensor, Some connections and transformations on a Riemannian manifold, Sectional curvature, and Shur's theorem.

Suggested Text Book:

1. De, U. C., & Shaikh, A. A. (2007). *Differential geometry of manifolds*. New Delhi: Narosa Publishing House.

Suggested References Books:

1. Boothby, W. M. (1986). *An introduction to differentiable manifolds and Riemannian geometry*. (2nd Ed.). Orlando, Fla: Academic Press.
2. Conlon, L. (2008). *Differentiable manifolds*. (2nd Ed.). Boston: Birkhäuser.
3. Hicks, N. J. (1975). *Notes on differential geometry*. London: Van Nostrand Reinhold.
4. Mishra, R. S. (1965). *A course in tensors with applications to Riemannian geometry*. Allahabad [India: Pothishala Private Ltd.
5. Tu, L. W. (2011). *An Introduction to Manifolds*. New York, NY: Springer New York.
6. Willmore, T. (1972). *An introduction to differential geometry*. Oxford: Clarendon Press.

Suggested E-learning material:

1. NOC: Differential Calculus in Several Variables: https://nptel.ac.in/courses/111104092/
2. NOC: Multivariable Calculus: https://nptel.ac.in/courses/111107108/
3. NOC:Calculus of One Real Variable: https://nptel.ac.in/courses/109104124/

MATH 601 Advanced Graph Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand and apply the fundamental concepts in graph theory.
- Recognize and express the mathematical ideas graphically.
- Acquire ability to apply graph theory based tools in solving practical problems.
- Improve the proof writing skills.
- Develop mathematical maturity.
- Understand some applications of graph theory to practical problems and other areas.

Section A

Basic concepts of graph theory, Directed graph, Euler graph, Hamiltonian graph, Matrix representation of graphs, Shortest path in a weighted graph, K-connected and K-edge-connected graphs, Planar graphs, Coloring of graphs, Vertex coloring of graphs, Edge coloring of graphs, Vizing's theorem.

Trees: Rooted trees, Spanning tree and Cut set, Minimum-spanning tree, Flow network in a graph, max-flow- min cut theorem.

Section B

Blocks: Bridges and blocks, Block graph and cut-point graph, Partitions, Factorization: 1-Factorization, 2-Factorization, Arboricity.

Covering: Covering and independence, Critical points and lines.

Groups: The automorphism group of a graph, Operations on Permutation graphs, the group of a composite graph, Graphs with a given group, Symmetric graphs, Highly symmetric graphs (self reading).

Section C

Enumeration: Labeled Graphs, Polya's enumeration theorem, Enumeration of graphs, Enumeration of trees, Matchings in bipartite graphs, Hall's matching theorem, Ramsey's theorem, Ramsey numbers, Eigenvalues of graphs**.**

Suggested Text/ Reference Books:

1. Deo, N.S. (2002). *Graph Theory*, Prentice Hall of Indi.
2. West, D.B. (2001*). Introduction to Graph Theory*, Prentice-Hall of India,.
3. Harary, F. *Graph Theory*, Narosa Pub. House.
4. Chartrand, G.and Zhang, P. (2011). *Introduction to Graph Theory*, Tata McGraw-Hill.

Suggested E-learning material

1. Basic concepts in graph theoryhttps://nptel.ac.in/downloads/111104026/
2. Basic concepts in graph theory http://home.iitk.ac.in/~arlal/book/mth202.pdf
3. Euler graph, Hamiltonian graph, connectivity and coloring http://www.math.kit.edu/iag6/lehre/graphtheo2015w/media/lecture_notes.pdf
4. Ramsey theoryhttp://math.mit.edu/~fox/MAT307-lecture05.pdf
5. Matchinghttp://www-math.mit.edu/~djk/18.310/Lecture-Notes/MatchingProblem.pdf
6. Open course in graph theory (All topics)
    a. https://swayam.gov.in/course/3795-graph-theory
    b. https://swayam.gov.in/course/4403-advanced-graph-theory

MATH 614 Finsler Geometry

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- use of purely metric methods in the investigation of various Finsler metrics that appear naturally in geometry, topology and convexity theory.

Section A

Minkowski norms, Finsler Metrics, Riemannian metrics, Product Finsler metric, Funk metric, Length Structure and Volume form, Zermelo Navigation Problem, Cartan Torsion, Matsumoto torsion.

Section B

Chern connections, Structural equations, Finsler metrics of Constant flag curvature, Bianchi Identities, Sprays, Shortest paths, projectively equivalent Finsler metrics, Projectively flat metrics.

Section C

Parallel vector fields, Parallel translations, Berwald metrics, Landsberg metrics, S-curvature, Distorsion and S-curvature, Randers metrics of Isotropic S-curvature, Riemannian Curvature, Flag curvature.

Text Books:

Chern, S. S., & Shen, Z. (2005). *Riemann Finsler Geometry, Nankai Tracts in Mathematics*, Vol. 6. World Scientific Publishing Co. Pte. Ltd.

Reference Books:

1. Bao, D., Chern, S.S., & Shen, Z. (2000). *An Introduction to Riemann Finsler Geometry, Graduate texts in Mathematics 200,* New York: Springer- Verlag.
2. Antonelli, P. L., Ingarden, R. S., & Matsumoto, M. (1993). *The theory of sprays and Finsler spaces with Applications in Physics and Biology*, FTPH 58, Kluwer Academic Publishers.

3. Matsumoto, M. (1986). *Foundations of Finsler geometry and Special Finsler Spaces*, Saikawa, Japan: Kaiseisha Press,.

4. Rund, H. (1959). *The Differential Geometry of Finsler spaces*, Berlin: Springer- Verlag.

Suggested E-learning material

1. Lectures on Differential Geometry: https://www.math.iupui.edu/~zshen/Research/papers/lecture.pdf

2. Lectures on Differential Geometry: https://www.worldscientific.com/worldscibooks/10.1142/4619#t=toc

MATH 619 Mathematical Cryptography

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the necessary concepts of number theory and complexity theory.
- Understand the need of cryptography and its impact on the society.
- Demonstrate the knowledge of one way functions and its concrete examples such as integer factorization and discrete logarithm.
- Understand the public key cryptosystems such as RSA and ElGamal.
- Know the concept of digital signature.

Section A

Basics of Number theory & Complexity theory, Introduction to cryptography, Classical cryptosystems and their cryptanalysis, Perfect

Secrecy, One way and trapdoor functions, Discrete logarithm problem, Integer factorization problem, Pseudo random bit generators, Block ciphers; DES, Triple DES.

Section B

Deffie-Hellman key exchange protocol, Public key encryption, RSA cryptosystem, Rabin's public key cryptosystem, El-Gamal cryptosystem, Knapsacks cryptosystem, Attack Models, Hash functions, Message authentication Code.

Section C

Digital Signatures; RSA, El-Gamal, DSA, Rabin's signature schemes, Entity Authentication, Zero knowledge protocols, Secret Sharing Schemes, Digital Cash, Elliptic curves, Identity based encryption and signature.

Suggested Text/ Reference Books:

1. Burton, D. M. (2012). *Elementary number theory*. (7th Ed.). New Delhi: McGraw-Hill Education.
2. Hoffstein, J., Pipher, J. C., & Silverman, J. H. (2014). *An introduction to mathematical cryptography*. (2nd Ed.). New York: Springer.
3. Trappe, W., & Washington, L. C. (2006). *Introduction to cryptography: With coding theory*. (2nd Ed.). Upper Saddle River, N.J: Pearson Prentice Hall.
4. Katz, J., & Lindell, Y. (2015). *Introduction to modern cryptography*. (2nd Ed.). Boca Raton: Taylor & Francis.
5. Forouzan, B. A., & Mukhopadhyay, D. (2011). *Cryptography and network security*. (2nd Ed.). New Delhi: Tata Mcgraw Hill Education Private Ltd.
6. Koblitz, N. (2006). *A course in number theory and cryptography*. (2nd Ed.). New York: Springer-Verlag.
7. Menezes, A., Van, O. P., & Vanstone, S. (1996). *Handbook of Applied Cryptography*. CRC Press.

Suggested E-learning material:

1. Lecture Notes on Number Theory: https://nptel.ac.in/courses/111103020/
2. Video Lecture on Number Theory: https://bit.ly/2ToTdjZ
3. Video Lecture on Cryptography: https://nptel.ac.in/courses/106105031/

STAT 504 Clinical Trials

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Identify and classify different types of trial designs when reading a trial report.
- Understand the essential design issues of randomized clinical trials.
- Appreciate three possible sources of errors that could lead to erroneous trial results.
- Understand the basic statistical principles, concepts, and methods for clinical data analysis and reporting; and
- Understand some frequently used terms in clinical trials.
- Understand the relative contributions of clinical judgment and clinical trials in evaluating new medical therapies.

Section A

Introduction to clinical trials. Overview of phase I-IV trials. Design consideration of clinical trials: Patient selection, selection of controls, statistical consideration. Randomization and blinding. Sample size estimation, recruitment of study participants.

Section B

Designs for clinical trials: Parallel, crossover, Cross-sectional, longitudinal, titration, enrichment designs. Classification of clinical trials: Multicentre, active control combination, equivalence trials. Concept of surrogate endpoints. An introduction to meta analysis of clinical trials.

Section C

Group sequential methods in clinical trials. Pollock's and O'Brien & Fleming's tests (with properties). Group sequential tests for binary data, survival data. Analysis for categorical data.

Text/ Reference Books:

1. Piantadosi, S. (1997). *Clinical trials. A methodological perspective*. New York: John Wiley and Sons, Inc.
2. Jennison, C., & Turnbull, B. W. (2000). *Group sequential methods with applications to clinical trials*. Boca Raton: Chapman & Hall.
3. Friedman, L. M., DeMets, D. L., & Furberg, C. D. (1998). *Fundamentals of clinical trials*. New york: Springer.
4. Fleiss, J. L. (2011). *Design and Analysis of Clinical Experiments*. New York, NY: John Wiley & Sons.
5. Marubini, E., & Valsecchi, M. G. (2005). *Analysing survival data from clinical trials and observational studies*. Chichester, West Sussex: John Wiley & Sons.
6. Chow, S.-C., & Liu, J. (2014). *Design and analysis of clinical trials: Concepts and methodologies*. Hoboken, N.J: John Wiley & Sons.

Suggested E-learning Resources

1. Clinical Trials http://www.esourceresearch.org/eSourceBook/Clinical-Trials/1LearningObjectives/tabid/192/Default.aspx
2. Clinical Trials as Research https://newonlinecourses.science.psu.edu/stat509/node/6/

STAT 505 Decision Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand a decision theoretic approach to the problem, evaluate a utility function, propose a conjugate family of prior distributions, evaluate Bayes and posterior risks and find the optimal solution.
- Solve Multilevel Decision Problems, Decision Process with sampling information
- Understand Basic Concept of the sampling time Markov decision process, telecommunication and queuing theory.

Section A

Concepts of process, Bayesian Procedure, Decision Functions, Different Decision Criterion for Decision Problems under risk and Uncertainty. Regret versus Loss Function, Expected Value of perfect Information, Utility and its Application in Decision Problems.

Section B

Multilevel (Multi-Stage) Decision problem, Principles of Diagramming and Locating of Optimal Strategy. Decision Analysis with Continuous Distribution for the Events.

Decision Process with Sampling Information: Simple Sampling and Binomial Sampling and with Updating the Prior Distribution of the Events (Use of Posterior Distribution). Decision Process and Normal Distribution of Event.

Section C

Basic Concepts of the Sampling time Markov Decision process Examples, Stationary Policies, Average Cost Criterion, Policy- Iteration Algorithm,

Linear Programming Formulation Procedure and Comparison of Linear Programming Formulation Procedure and Policy Iteration Algorithm for Solving an Infinite Stage Markov Decision Problem. Simple Concept of Semi Markov Decision Process. Application of Markov Decision Process to Inventory Management, Maintenance, Manufacturing Process, Telecommunication and Queuing theory.

Suggested Text/ Reference Books:

1. Baird, B. F. (1989). *Managerial decisions under uncertainty: An introduction to the analysis of decision making*. New York: J. Wiley. (chapters - 7,8,10,12),
2. Buchanan, J. T. (1982). *Discrete and dynamic decision analysis*. Chichester: Wiley.
3. Bunn, D. W., & Bunn, D. W. (1984). *Applied decision analysis*. New York: McGraw-Hill Book.
4. French, S. (1986). *Decision Theory: An Introduction to the Mathematics of Rationality*. Ellis Horwood.
5. Jones, J. M. (1977). *Introduction to decision theory*. Homewood, Illinois [etc.: Richard D. Irwin. (chapters -5,6,8,9,10,11).
6. Tijms, H. C. (1998). *Stochastic models: An algorithmic approach*. Chichester [u.a.: Wiley. (chapters - 2 & 3),

Suggested E-learning Resources

1. Decision Theory; platform: http://www.utdallas.edu/~ mbaron/7330/

STAT 508 Distribution Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Formulate the statistical models for real data sets arising in various fields in order to analyze in respect of various useful characteristics of the populations
- Develop problem-solving techniques needed to accurately calculate probabilities.
- Identify the distribution of random variable under various discrete and continuous distributions.
- Calculate probabilities, moments and other related quantities based on given distributions.
- Determine the probability distribution after transformation.
- Understand how to use non-central distributions in real life problems.

Section A

Random Experiments and its sample space, random vatriables, cdf, pdf and pmf, absolutely continuous and discrete distributions, mixtures of probability distributions. Some common distributions like Bernoulli, Uniform, Binomial, Poisson, Geometric, Rectangular, Exponential, Normal, Cauchy, hypergeometric, multinomial, Laplace, Negative Binomial, Beta, Gamma, Lognormal and Compound Poisson distribution Weibull distribution.

Section B

Distributions of functions of random variables: Transformations, moments, m.g.f.., p.g.f, Independence of random variables, Convolutions, Conditional expectations and variances.

Random vectors, joint distributions, joint m.g.f., mixed moments and variance- covariance matrix. Correlation and regression.

Section C

Sampling distributions of statistics from univariate normal random samples such as linear and quadratic forms. Fisher's Cochran theorem. Non central chi-square, t and F distributions.

Suggested Text/ Reference Books:

1. Mood, A. M. F., Graybill, F. A., & Boes, D. C. (2013). *Introduction to the theory of statistics*. New Delhi: McGraw-Hill Education (India.
2. Johnson, N. L., Kotz, S., & Balakrishnan, N. (1995). *Continuous univariate distributions-Vol. 2*. Wiley & Sons.
3. Johnson, N. L., Kemp, A. W., & Kotz, S. (2005). *Univariate Discrete Distributions*. John Wiley & Sons.

Suggested E-learning Resources

1. Probability Distribution- nptel.ac.in/courses/111105041/
2. Distribution Functions-https://epgp.inflibnet.ac.in/ahl.php?csrno=34
3. Introduction to Probability- https://ocw.mit.edu/resources /res-6-012-introduction-to-probability-spring-2018

STAT 522 Econometric Models

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Construct econometric models from economic models.
- Detect influential observations and perform robust regression.
- Estimate regression models when the dependent variable is nominal, ordinal or a quantile.
- Fit distributed lag model when the data is time series.
- Diagnose the identifiability of a simultaneous equation model.
- Estimate a simultaneous equation system.

Section A

Nature of Econometrics, Review of linear regression models, polynomial regression model. Stepwise Regression, Lasso Regression, Model Selection Methods: AIC, BIC, Mallow's Cp, Cross-validation, Regression regularization methods.

Influential observations: Standardized and Studentized residuals, Cook's distance, DFFITS, DFBETAS, COVRATIO. Robust regression techniques: LAD and LMS regression.

Section B

Logit and Probit models: binary response model, multinomial choice models: ordered and unordered response models. Censored regression, truncated regression models.

Poisson regression: estimation and prediction. Introduction to Generalized linear model.

Introduction to quantile regression and non-parametric regression. General non-linear regression: Assumptions, Least squares estimation, Testing.

Section C

Distributed lag models: Finite polynomial lags, determination of the degree of polynomial. Infinite distributed lags, adaptive expectations and partial adjustment models, determination of lag length. Methods of estimation.

Simultaneous equation models: concept of structural and reduced forms, problem of identification, rank and order conditions of identifiability. Limited information and full information estimation methods.

Suggested Readings

1. Baltagi, B. H. (2007). *Econometrics*. Springer Science & Business Media.
2. Gujarati, D. N. (2003). *Basic econometrics*. McGraw Hill.
3. Johnston, J., & DiNardo, J. E. (2007). *Econometric Methods*. McGraw-Hill.
4. Montgomery, D. C., Peck, E. A., & Vining, G. G. (2006). *Introduction To Linear Regression Analysis, 3rd Ed*. Wiley India Pvt. Limited.

5. Rawlings, J. O., Pantula, S. G., & Dickey, D. A. (1998). *Applied Regression Analysis: A Research Tool* (2nd Ed.). New York: Springer-Verlag.

6. Wooldridge, J. M. (2008). *Introductory Econometrics: A Modern Approach*. Cengage Learning.

7. William H. Greene (2012). *Econometric Analysis* (7th Ed.). Pearson Education limited.

Suggested E-learning Resources

1. Lecture Notes on Regression Analysis by Shalabh, IITK: http://home.iitk.ac.in/~shalab/course5.htm

2. An article on "Understanding logistic regression analysis" by Sandro Sperandei : https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3936971/

3. Lecture Notes on "Econometrics": https://ocw.mit.edu/courses/economics/14-382-econometrics-spring-2017/lecture-notes/

STAT 511 Non-Parametric Inference and Sequential Analysis

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Solve hypothesis testing problems where the conditions for the traditional parametric inferential tools to be applied are not fulfilled.
- Build non-parametric density estimates.
- The application of sequential statistical techniques.
- Critically examining sequential procedures for appropriate statistical analyses.

Section A

Distribution free and non-parametric methods, order statistics, joint distribution of order statistics, marginal distribution of order statistics, distribution of median and range, exact moments, confidence interval, estimates for population quantities, Exact null distribution of R moments of the null distribution of R, test based on total number of runs, chi-square goodness of fit test, empirical distribution function.

Section B

Ordinary sign test, Wilcoxon signed rank test, Kolmogorov Smirnov one sample & two sample test and their merits and demerits, Median test, Kruskal- Wallis one way analysis of variance by ranks, McNemar change test.

Section C

Sequential analysis Wald's SPRT, properties of SPRT, OC and ASN functions of SPRT, Applications of SPRT, Testing of mean of a binomial distribution, Testing of mean of a normal distribution with known & unknown standard deviations.

Sugessted Text/ Reference Books:

1. Siegel, S., & Castellan, N. J. (1988). *Non parametric statistics for the behavioral sciences*. New York, N.Y: McGraw-Hill.
2. Casella, G., & Berger, R. L. (2017). *Statistical inference*. Belmont, CA: Brooks/COle Cengage Learning.
3. Wald, A. (2004). *Sequential analysis*. Mineola, N.Y: Dover Publications.
4. Gibbons, J. D., & Chakraborti, S. (2003). *Nonparametric Statistical Inference*. CRC Press.

Suggested E-learning material

1. Statistical Methods for Scientists and Engineers- Non Parametric Methods: https://nptel.ac.in/courses/111105077/29.
2. Statistics for Applications: https://ocw.mit.edu/courses/mathematics/18-650-statistics-for-applications-fall-2016/

STAT 513 Regression Analysis

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the concept of regression and the underlying assumptions.
- Estimate least squares estimate of regression coefficients.
- Perform testing of complete regression model and subset of regression model.
- Measure the goodness of the model.
- Check the validity of the assumptions for a real data.
- Find a suitable remedy to reduce the effect of violation of any assumption.
- Include a qualitative variable as regressors in a regression model using dummy variables.
- Check the model for specification errors and its testing.
- Understand the concept of outlier, leverages and influential observations.
- Understand the concept of a simple logistic regression and make interpretations.

Section – A

Review of the two-variable linear model, p-variable linear model: underlying assumption, ordinary least squares estimators, set of linear hypothesis: Testing a single coefficient, testing the significance of a subset of coefficients, testing the significance of the complete regression. Confidence estimation, R2 and adjusted R2. Residual Analysis.

Section B

Problems of multicollinearity: its detection and remedies, ridge estimator, PCR estimator, Use of extraneous information in terms of exact and stochastic linear restrictions. Estimation of parameters by generalized least squares in models with non spherical disturbances: heteroscedasticity of disturbances and the problem of autocorrelation.

Section C

Dummy Variables in Linear Regression Models, tests for structural break, Specification Errors, Nonlinear Associations and Interaction Terms, Influential Observations: Leverage Points and Outliers,A Brief Introduction to Logistic Regression.

Text Book:

1. Johnston, J. (1984). *Econometric Methods*, McGraw Hill Kogakusha Ltd.

Reference Books:

1. Hoffmann, J. P., & Shafer, K. (2015). *Linear regression analysis: Assumptions and applications*.
2. Draper, N. R., & Smith, H. (1998). *Applied regression analysis*. New York, N.Y: Wiley.

Suggested E-learning Resources

1. The resources site for the book 'Introductory Econometrics for Finance, 3rd edition' by Chris Brooks https://www.cambridge.org/us/academic/textbooks/introductory-econometrics
2. Lecture Notes on “Econometric Theory”: https://nptel.ac.in/ courses/111104072/
3. Course material on “Econometrics”: https://ocw.mit.edu/courses/ economics/14-32-econometrics-spring-2007

STAT 603 Bayesian Inference

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Calculate simple likelihood function and use relative frequencies to estimate probabilities and conditional probabilities.
- Calculate posterior probabilities using Bayes' theorem
- Describe the role of the posterior distribution, the likelihood function and the posterior distribution in Bayesian inference about a parameter.
- Explain in detail the Bayesian framework for data analysis and its flexibility and be able to demonstrate when the Bayesian approach can be beneficial.
- Develop, analytically describe, and implement both single and multi parameter probability models in the Bayesian framework.
- Demonstrate the role of the prior distribution in Bayesian inference and be able to articulate the usage of non-informative priors and conjugate priors.
- Show high level Interpretation of Bayesian Analysis Results and be able to readily perform Bayesian model evaluation and assessment.

Section A

Bayes Theorem for random variables; non-informative and improper prior distributions for location, scale and location scale parameters; Jeffery's priors. Hartingan's priors, maximum entropy priors; Bayes sufficiency, Factorization theorem; natural conjugate priors; posteriors distribution and normal approximations to posterior distribution, Bayes principle and Bayes risk; generalized maximum likelihood estimation; Bayes point estimate; Credible regions; H.P.D. credible regions.

Section B

Finite action problem and hypothesis testing; prior and posterior odds ratio; Bayes factor; Lindley's paradox, two sample testing problems for the parameters of normal population; predictive density function; point and interval predictors.

Section C

Empirical Bayes estimation, determination of prior distribution from past data; linear Bayes estimate, hierarchical Bayes analysis (Normal context); Preposterior analysis and determination of optimal fixed sample size; general discussion on Bayes computation (without proof).

Suggested Text/ Reference Books:

1. Bansal, A.K. (2007). *Parametric Bayesian Inference.* New Delhi: Narosa Publishing House.
2. Aitchison, J. and Dunsmore, I.R. (2009). *Statistical Prediction Analysis*, Cambridge, GBR: Cambridge University Press.
3. Berger, J.O (2010). *Statistical Decision Theory and Bayesian Analysis*, New York, NY: Springer.
4. Box, G.E.P. and Tiao, G.C. (2011). *Bayesian Inference in Statistical Analysis*, New York: John Wiley & Sons.
5. Degroot, M.H. (2004). *Optimal Statistical Decisions*. New York, NY: McGraw-Hill.
6. Bernando, J.M. and Smith, A.F.M. (2009). *Bayesian Theory*, Chichester: Wiley.
7. Ghosh, J. K., Delampady, M., & Samanta, T. (2007). An introduction to Bayesian analysis: theory and methods. Springer Science & Business Media.

Suggested E-learning material

1. Bayesian Statistics: From Concept to data analysis https://www.coursera.org/learn/bayesian-statistics
2. Introduction to Bayesian Statistics https://www.statistics.com /bayesian-statistics/

STAT 609 Population Sciences

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Identify principle sources of population data and assess their strengths and weaknesses.
- Able to evaluate of human development index.
- Construct and interpret life tables.
- Aware various population policies and programs.
- Calculation and interpretation of the principal demographic measures, and standardize these measures for comparison.
- Understand the significance of age- sex structures and their implications on population change, including the effects of changing birth, death and migration rates, and demonstrate their influences on age structure.
- Understand the concept of urbanization on the economic growth of the contrary.
- Estimate and project the population by different methods.

Section A

Definition of demography, Population Sciences, Source of population data, Census, Civil Registration System (CRS), Sample Registration Scheme (SRS), National Sample Survey (NSS), Demographic surveys and other sources (Nature and limitation of the data from each of the sources), Population Composition and change, Concept of aging, Population Theories- Theories of population growth-Malthus to Modern, theory of Demographic Transition, Theories related to fertility, migration and urbanization, Population, Development and Environment, Population and Gender, HDI.

Section B

Nuptiality& Fertility (Concepts, Measures Determinants of fertility). Mortality, Morbidity& Health (Concepts &Measures). Life Tables (Basic concepts, type and forms of life table),lexis diagram, Model life table. Reproductive Health, Migration and Urbanization (basic concepts, types, measures). Determinants and Consequences of migration, trends and pattern of urbanization in India, Issues in urbanization and urban problems in developing countries with focus on India.

Section C

Population estimation: Inter-Censual & Post Censual, Methods of population projection population policies and programmes. Population policies in the context of growth, structure, distribution and quality of life:policies related to medical termination of pregnancy (MTP), age at marriage, Sex Determination tests. National & state population policies in India. Evolution of family welfare programme in India. Programme Component and organization at different levels (National, State, District). Goals and achievements of the family welfare programme. Impact Assessment.

Suggested Text/ Reference Books:

1. Cox, P. R. (2009). *Demography* (6th. ed.). GBR Cambridge University Press.
2. Pathak, K.B.& Ram, F. (2019) *Techniques of Demographic Analysis* (2nd. ed.). Himalaya Publishing House.
3. Srinivasan, K., Saxena, P. C., & Kanitkar, T. (1979). *Demographic and Socio-economic Aspects of the Child in India*. Himalaya Publishing House.
4. Ramkumar, R. (2006). *Technical Demography*. New Age International.
5. Bhinde, A. A. & Kanitker, T. (2018). *Principles of Population Studies* (19th. ed.). Himalaya Publishing House.
6. Sinha, V. C., & Zacharia, E. (1984). *Elements of demography*. Allied Publishers.

Suggested E-learning material

1. Demographic data; Platform: National Family Health Survey, India http://rchiips.org
2. Population Studies; Platform; e-PG Pathshala https://epgp.inflibnet.ac.in/loaddata.php?action=loadpaperlist1&maincat=453
3. Demography ; Platform: University Library - The University of Adelaide

   https://www.adelaide.edu.au/library/
4. Demography; Platform: MIT OPENCOURSEWARE https://ocw.mit.edu/index.htm

STAT 613 Time Series Modeling

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Estimate and eliminate trend and seasonality in a time series
- Fit stationary and non-stationary time series model to a series
- Understand the concept of testing for parameter stability of a time series model
- Demonstrate fitting of multivariate ARMA model to series
- Understand the concept of cointegration analysis and procedure for two variable models.
- Understand the concept of Vector autoregression and causality.
- Understand the concept of volatility in a series and related models.

Section A

Review of Time series analysis: Estimation and elimination of of trend and Seasonal component. Simple time series models and their applications, Wald decomposition theorem, Estimation of AR/MA/ARMA models, Autocorrelation and partial autocorrelation functions. Diagnostic tests (AIC, BIC criterion), Forecasting ARMA processes.

Section B

Non stationary time series models (ARIMA): Estimation and forecasting. Testing of parameter stability, Multivariate time series models (ARMA), Cointegration: a general cointegrated system, two variable model: Engle-Granger method, Johansen procedure; error correction model and tests for cointegration.

Section C

Vector autoregression and Granger causality. Non-linear models: Volatility, Autoregressive conditional heteroscedastic (ARCH/GARCH) models, different interpretations, various generalizations, estimation and testing.

Suggested Text/ Reference Books:

1. Brockwell, Peter J., & Davis, Richard A. (2013). *Introduction to Time Series and Forecasting*. Springer Verlag.
2. Fuller, W. A. (2009). *Introduction to Statistical Time Series*. Hoboken: John Wiley & Sons, Inc.
3. Chatfield, C. (1999). *The analysis of time series: An introduction*. Boca Raton: Chapman & Hall/CRC.
4. Mills, T. C. (2001). *Time series techniques for economists*. Cambridge: Cambridge Univ. Press.

Suggested E-learning material

1. Econometric Modeling. Platform: https://nptel.ac.in/courses /110105053/29

2. Video lectures on Econometric Modeling: https://nptel.ac.in/courses/110105030/37
3. Video lectures on e-PG- Pathshala, Subject: Statistics, Paper Name: P-14. Econometrics and Financial Time Series https://epgp.inflibnet.ac.in/ahl.php?csrno=34

MATH 543 Fuzzy Logic and Belief Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- learn crips and fuzzy set theory.
- decide the difference between crips set and fuzzy set theory.
- make calculation on fuzy set theory.
- recognize fuzzy logic membership function.
- recognize fuzzy logic fuzzy inference systems
- make applications on Fuzzy logic membership function and fuzzy inference systems.
- utilize fuzzy logic approach to problems arising in the field of Operations Research, Computer Science and Engineering.
- be able to formulate logical expressions, fuzzy logic to solve a variety of problems related to real scenarios
- be able to apply defuzzification methods.

Section A

Basic concept of Fuzzy Logic: Introduction to fuzzy set, membership function, Various forms of membership functions, type of fuzzy sets, LR-representations of fuzzy sets, properties of fuzzy sets (support, cardinality, alpha-cut set, convexity).Operations on Fuzzy sets: Union, Intersection, complement, combinations of operations.Fuzzy extension principle,

Fuzzy Relations: fuzzy cartesian product and composition, Crisp versus fuzzy relations, binary fuzzy relation, fuzzy equivalence relations, fuzzy compatibility relations, fuzzy ordering relations.Fuzzy graphs, Fuzzy morphism (homomorphism), Fuzzy relation equations.Fuzzy Numbers: Definitions and types of fuzzy numbers, interval analysis in arithmetic, triangular and trapezoidal types, Arithmetic operations on fuzzy numbers.Fuzzy Function: Introduction to fuzzy function, type of fuzzy function, fuzzy extrema of function, differentiation and integration of fuzzy function.

Section B

Fuzzy Logic: Classical logic, logic variable, logic function, truth tables, tautology and inference rule, Linguistic variables. Predicate logic, Quantifier, fuzzy expression, operators in fuzzy expression, fuzzy predicate, fuzzy modifier, fuzzy truth qualifier. Fuzzy if-then rules: Basics of fuzzy rules, fuzzy mapping rules, fuzzy implication rules. Fuzzy Decision Making: Introduction, multistage decision making, fuzzy ranking method, fuzzy linear programming, fuzzy transportation problems Fuzzy System: Introduction to fuzzy system. Defuzzification methods: centre of area (or centre of gravity or centroid), centre of maxima, mean of maxima. Fuzzy controllers: an overview of fuzzy controller. Fuzzy Systems and Neural Network: Introduction to neural network, fuzzy neural networks.

Section C

Probability, Uncertainty and Fuzzy Measures: Probability verses Possibility, Fuzzy event, Crisp probability of fuzzy event and fuzzy probability of fuzzy event, Level of uncertainty, Measure of fuzziness: (i) using Shannon's entropy formula and (ii) using metric distance.

Belief Theory: Evidence Theory- Mathematical Theory of evidence, Introduction to Shafer's Belief Theory, Belief representation: mass of belief, belief measure, plausibility measure, properties of belief function-relation between belief and plausibility measure, Dempster's Rule of Combination, Applications of Fuzzy logic and fuzzy set theory in Operations Research, Computer Science and Engineering fields.

Suggested Text Books:

1. Lee, K. H. (2005). *First course on fuzzy theory and applications*. Berlin: Springer-Verlag
2. Klir, G. J., & Yuan, B. (2003). *Fuzzy sets and fuzzy logic: Theory and applications*. New Delhi: Prentice Hall of India.

SuggestedReference Books:

1. Klir, G. J., & Folger, T. A. (2010). *Fuzzy sets, uncertainity and information*. New Delhi: PHI Learning Private Ltd.
2. Yen, J., &Langari, R. (2005). *Fuzzy logic: Intelligence, control and information*. Pearson Education.
3. Shafer, G. (1976). *A mathematical theory of evidence*. Princeton: Princeton University Press.
4. Mukaidono, M. (2010). *Fuzzy logic for beginners*. Singapore: World Scientific.
5. Nguyen, H. T., & Walker, E. A. (2006). *A first course in fuzzy logic*. Boca Raton, Fla: Chapman & Hall/CRC.

Suggested E-learning material:

1. Introduction to Fuzzy Logic(Videos)https://nptel.ac.in/ courses/106105173/2
2. Fuzzy Logic: Introduction (PDF) http://cse.iitkgp.ac.in/~ dsamanta/courses/sca/resources/slides/FL-1%20Introduction.pdf

MATH 546 Inventory Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Comprehend the dynamics of inventory management's principles, concepts, and techniques as they relate to the entire supply chain (customer demand, distribution, and product transformation processes),

- Understand the methods used by organizations to obtain the right quantities of stock or inventory,
- Familiarize themselves with inventory management practices.
- Optimize different case studies requires efficient methods and practices to address inventory management problems.
- Understand the behavior of the inventory parameters after some time using simulation techniques.

Section A

Concepts of Inventory, Classification of inventory models, EOQ model, EPQ model, EOQ model with shortages, EPQ model with shortages, EOQ model with constraints: Quantity discounts, Floor Constraints, Investment Constraint. Sensitivity analysis in inventory models.

Section B

Stochastic Inventory Models and Extensions without and with lead time. Power demand pattern inventory model,

Introduction to Just In Time (JIT) and Vendor Managed Inventory (VMI).

Section C

Simulation in Inventory system, Classification of items viz: ABC, VED, FNSD, HML, SDE, XYZ, Case studies in inventory control.

Suggested Books:

1. Hadley, G., Whitin, T. M.. (1963). *Analysis of inventory systems.* Englewood Cliffs, N.J.: Prentice-Hall.
2. Naddor, E. (1984). *Inventory systems*. Malabar, Fla: R.E. Krieger.
3. Waters, D. (2008). *Inventory Control And Management, 2Nd Ed*. Wiley India Pvt. Limited.

Suggested E-learning material:

1. Inventory Models costs, EOQ model(Lecture PDF) https://nptel.ac.in/courses/110106045/9
2. Inventory management(PDF) https://ocw.mit.edu/courses/engineering-systems-division/esd-260j-logistics-systems-fall-2006/lecture-notes/

MATH 555 Queueing Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the principles and objectives of model building based on Markov chains.
- Analyze the queueing situations.
- Understand the mathematical tools that are needed to solve queueing problems.
- Identify and develop queueing models from the verbal description of the real system.

Section A

Introduction of stochastic processes, Markov process, Markov Chain, Poisson process with its properties and related distributions (without proof) and birth-death process. Objectives and different characteristics of a Queueing system. Performance measures. Steady state solution of Markovian queueing models: M/M/1 and M/M/c. and their performance measures.

Section B

Steady State solution of $M/E_k/1$ and $E_k/M/1$ queueing models with their performance of measures. The transient solution of M/M/1 and M/M/∞ Queueing models including busy period distribution.

Section C

Imbedded Markov chain technique and its use to solve the Queueing models: M/G/1 and GI/M/1. Bulk queuing models: $M^{[X]}/M/1$ and $M/M^{[Y]}/1$. Different design and control policies for Markovian Queueing models. Simulation procedures: Data generation and Book- keeping aspects.

Suggested Text Books:

1. Gross, D., & Harris, C. M. (1985). *Fundamental of Queueing Theory*. (2^{nd} ed.). John Wiley.

2. Michel, E. W. (1994). *Communication and Computer Networks Modeling with discrete Time queues*. IEEE Computer Society Press. (Chapter 4).

Suggested Reference Books:

1. Cooper, R. B. (1981). *Introduction to Queuing Theory*. (2nd ed.). North Holland, Elsevier.
2. Cox, D. R. & Smith, W. l. (1961). *Queues*. Mathuen& Co. Ltd.
3. Kleinrock, L. (1975). *Queuing System*. (Vol. 1). John Wiley.
4. Medhi, J. (1991). *Stochastic Models in queuing Theory*. Academic Press.
5. Satty, T. L. (1961). *Elements of Queuing Theory with Applications.* Tata McGraw Hill.

Suggested E-learning Material:

1. Queuing Systems, NPTELhttps://nptel.ac.in/courses/ 117103017/1
2. Introduction to stochastic process and applications, NPTELhttps://nptel.ac.in/courses/110104024/1
3. Stochastic Process and Time series, ePATHSHALAhttps:// epgp.inflibnet.ac.in/ahl.php?csrno=34

STAT 524 Reliability and Renewal Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the importance of validity and reliability assessment and the link between the two.
- Estimate the reliability function and mean time to failure for different types of systems
- Analyze statistical experiments leading to reliability modeling.
- Estimate life length distributions, using complete or censored data.

- Identify reliability testing components.
- Apply reliability theory to assessment of reliability in engineering design.
- Analyze non-repairable systems of independent components, with and without redundancy
- First look at what a random process is and then explain what renewal processes are.
- Describe, derive, and prove important theorems and formulas for renewal theory
- Use renewal theory to solve problems where Poisson is not a realistic process

Section A

Concept of Reliability. Classes of Life time distributions. Evaluation of Reliability function, Shape of Reliability function. System, Reliability Evaluation : Series & Parallel system, partially redundant system, standby system with perfect switching/imperfect switching, (k,n) system, Bridge Structure. Availability theory and its molding for various configurations. Introduction to Software Reliability.

Section B

Reliability models of maintained systems. Reliability Allocation Problems, Discrete Replacement Policies : Age, Block, Policies, Preventive Maintenance Policies, Corrective Maintenance Policies, Concept of minimal repair, Notions of aging.

Section C

Renewal Theory, Distribution of number of renewals & moments, Recurrence time & its limiting distribution. Application of Renewal Theory, Solutions of Renewal type equations, Optimization problem with respect to system reliability.

Text Books

1. Sinha, S. K. (1986). *Reliability and life testing*. New York: Wiley.
2. Gertsbakh, I. B. (2009). *Reliability theory: With applications to preventive maintenance*. New Delhi: Springer.
3. Cox, D. R. (1982). *Renewal theory*. London: Chapman and Hall.
4. Lewis, E. E. (1996). *Introduction to reliability engineering*. New York, NY: Wiley.

Reference Books

1. Barlow, R. E., & Proschan, F. (1975). *Statistical theory of reliability and life testing*. New York: Holt, Rinehart and Winston.
2. Jardine, A.K.S. (1973). *Maintenance, Replacement and Reliability*. UK: Pitman Publication.
3. Medhi, J. (2009). *Stochastic Process* (3rd Ed.). New Age International, 2009.

Suggested E-learning Resources

1. 2011 Lecture 17: Modules, Systems, and Reliability: https://ocw.mit.edu/courses/mechanical-engineering/2-627-fundamentals-of-photovoltaics-fall-2013/lecture-videos-slides/2011-lecture-17-modules-systems-and-reliability/
2. Probability Theory and Applications: Lecture 40- Reliability of Systems: https://nptel.ac.in/courses/111104079/40

MATH 539 Fields and Galois Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the concepts of field extension and appreciate its importance.
- Understand different types of extensions.

- Find the Galois group for some extension fields.
- Know the link between field theory and group theory.
- Demonstrate the solvability of quadratic, cubic and quartic equations by radicals.

Section A

Fields, prime subfields, Extension fields, algebraic extensions, simple extensions, transcendental extension, minimal polynomial, Kronecker's Theorem, splitting fields, uniqueness of splitting fields and algebraic closures.

Section B

Finite fields, existence and uniqueness of finite fields, Normal and separable extensions, perfect fields, Automorphisms of field, fixed fields, Galois group, F–conjugate, Frobenius map,character, linear independence of characters.

Section C

Fundamental theorem of Galois theory, cyclotomic extensions and abelian extensions, cyclotomic polynomials, cyclic extension, radical extension, solution of quadratic, cubic and quartic equations by radicals.

Suggested Books:

1. Howie, J. M. (2006). *Fields and Galois theory*. London: Springer.
2. Escofier, J.-P. (2001). *Galois theory*. New York: Springer.
3. Gallian, J. A. (2013). *Contemporary abstract algebra*. (8th Ed.). Boston, MA: Brooks/Cole Cengage Learning.
4. Dummit, D. S. & Foote, R. M. (2004)*Abstract algebra*(3rd Ed.).New Jersey: Wiley.
5. Sen, M. K., Ghosh, S., Mukhopadhyay, P. &Maity, S. K. (2019)*Topics in abstract algebra*(3rd Ed.). University Press.
6. Morandi, P. J. (2003). *Field and Galois theory*. Beijing: Beijing World Pub.

Suggested E-learning Material:

1. Notes on Galois Theory: www.math.iitb.ac.in/~srg/ Lecnotes/*galois*.pdf
2. Lecture Notes: https://nptel.ac.in/courses/111101001/

MATH 534 Coding Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the need of coding theory.
- Appreciate the applications of abstract and linear algebra in coding theory.
- Find the generator and parity check matrix of linear codes.
- Understand the main coding theory problem.
- Derive classical bounds of codes and the distance of the code.
- Understand cyclic codes and their decoding.

Section A

Communication channels, maximum likelihood decoding,Hamming distance, minimum distance decoding, distance of a code,finite fields, structure of finite fields, minimal polynomial, linear codes, Hamming weight, bases of linear codes, generator matrix and parity check matrix, encodingand decoding of linear codes, syndrome decoding.

Section B

The coding theory problem, lower bounds, Hamming bounds and perfect codes, singleton bound and MDS codes, nonlinear codes, Reed-Muller codes, subfields codes.

Section C

Cyclic codes: definitions, generator polynomials, generator and parity check matrices, decoding of cyclic codes, Burst-error-correcting codes, BCH codes: definitions, parameters of BCH codes, Decoding of BCH codes. Reed–Solomon codes, generalized Reed–Solomon codes, Goppa codes.

Suggested Text Book:

1. Ling, S., & Xing, C. (2004). *Coding Theory: A first Course*. Cambridge: Cambridge University Press.

Suggested Reference Books:

1. MacWilliams, F. J., & Sloane, N. J. A. (2007). *The theory of error-correcting codes*. Amsterdam: North-Holland.
2. Peterson, W. W., & Weldon, E. J. (2008). *Error-correcting codes*. (2nd Ed.). Cambridge, Mass: MIT Press.
3. Berlekamp, E. R. (2015). *Algebraic coding theory*. (Algebraic Coding Theory.) Singapore: World Scientific.
4. Huffman, W. C., &Pless, V. (2010). *Fundamentals of error-correcting codes*. Cambridge: Cambridge Univ. Press.
5. Hill, R. (2001). *A first course in coding theory*. Oxford: Clarendon Press.
6. Rhee, M. Y. (1989). *Error-correcting coding theory*. Singapore: McGraw-Hill.

Suggested E-learning Material:

1. Online Course on Coding Theory: https://onlinecourses.nptel.ac.in/noc17_ee07
2. Lecture Notes: https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-895-essential-coding-theory-fall-2004/

MATH 540 Fixed Point Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand various concepts in metric spaces such as completeness.
- Demonstrate standard examples of metric spaces and prove simple results related to them.
- Understand the proof of open mapping theorem and Closed graph theorem.

- Check the conditions for expansive and Nonexpansive Mappings, contractive and contraction mappings.
- Understand standard fixed-point theorems.
- To present the basic ideas of the theory, and illustrate them with a wealth of examples and applications in differential and integral equations.

Section A

Metrics space, Complete metric space, Convergence, Cauchy sequence and Completeness, Various concept in metric space, Normed linear space, Banach space, normed space and Hilbert space, open mapping theorem and Closed graph theorem, linear operator.

Section B

Lipschitz mapings,expansive and Nonexpansive Mappings, contractive and contraction mappings, Upper and lower semi continuity of maps, contractive and nonexpansive multivalued maps, Banach's contraction principle, Fixed point theorem of Schauder's and Kirk, Tarsiki's Fixed point theorem.

Section C

Banach Fixed point theorem for multivalued maps, Generalized Schauder Fixed point theorem. Existence of solutions of ordinary equations and systems of linear equations in several unknowns, applications in the theory of differential and integral equations.

Suggested Books:

1. Zeidler, E. (2000). *Nonlinear functional analysis and its applications: Vol 1*. New York: Springer.
2. Khamsi, M. A., & Kirk, W. A. (2001). *An introduction to metric spaces and fixed point theory*. New York: John Wiley & Sons.
3. Smart, D. R. (1980). *Fixed point theorems*. Cambridge: Cambridge University Press.
4. Istrătescu, V. I. (1981). *Fixed point theory: An introduction*. Dordrecht, Holland: D. Reidel Pub.

5. Agarwal, R. P., Meehan, M., &O'Regan, D. (2009). *Fixed point theory and applications*. Cambridge, UK: Cambridge University Press.

E-Resources

1. National Programme for Technology Enhanced Learning (NPTL)

   [https://nptel.ac.in/courses/111105037/]

MATH 545 Introduction to Dynamical Systems

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Describe the main features of dynamical systems and their realisation as systems of ordinary differential equations.
- Identify fixed points of simple dynamical systems, and study the local dynamics around these fixed points, in particular to discuss their stability.
- Use a range of specialised analytical techniques which are required in the study of dynamical systems.
- Describe dynamical systems geometrically and represent them graphically via phase plane analysis.
- Find fixed points and period orbits of discrete dynamical systems, and find their stability.
- Do graphical analysis of 1D discrete dynamical systems.
- Understand the basic properties of a chaotic dynamical system.

Section A

Introduction to Dynamical Systems: Background and examples, dynamical systems, attractors and invariant sets.

Non-linear Systems-local analysis: the fundamental existence-uniqueness theorem, The flow defined by a differential equation, Linearization, The

stable manifold theorem, The Hartman-Grobman theorem, Stability and Liapunov functions, Saddles, Nodes, Foci, and Centers.

Section B

Non-linear Systems-global analysis: Dynamical systems and global existence theorem, Limit sets and Attractors, Periodic orbits, Limit Cycles, and Seperatrix cycles, the Poincare map, the stable manifold theorem for periodic orbits, the Poincare-Bendixon theory in R2, Lineard Systems, Bendixon's Criteria.

Section C

Discrete dynamical systems: finite dimensional maps, limit sets, Stability, Invariant manifolds, Runge-Kutta methods: the framework, linear decay, Lipschitz conditions, Dissipative systems, Generalized dissipative systems, Gradient system.

Suggested Books:

1. Perko, L. (2009). *Differential equations and dynamical systems*. (3rd Ed.). New York, NY: Springer.
2. Stuart, A. M., & Humphries, A. R. (1998). *Dynamical systems and numerical analysis*. Cambridge: Cambridge University Press.
3. Lynch, S. (2014). *Dynamical systems with applications using MATLAB*. (2nd Ed.). Cham: Birkhäuser.

MATH 533 Bio Mathematics

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- model the single species and two species systems.
- study the stability of these systems.
- Apply harvesting of the species.
- to model epidemics and analyse the dynamics

Section A

Continuous population Models for single species: Basic concepts. Exponential growth model, formulation, solution, interpretation, and limitations. Compensation and depensation. Logistic growth model, Continuous Growth Models, Insect out break Model: Spruce Budworm, Delay models, Linear Analysis of Delay Population Models: Periodic solutions. Harvesting a single Natural Population.

Section B

Continuous Models for interacting Population:Interaction between species: two species models, definition of stability, community matrix approach, Qualitative behavior of the community matrix, Competition: Lotka-Volterra models, Extension to Lotka-Volterra models, Competition in field experiments, Competition for space, Models for Mutualism. Predator-Prey interaction: Lotka-Volterra Models, dynamic of the simple Lotka-Volterra models, Role of density dependent in the Prey, Classic laboratory experiment on predator, predation in natural system. Some predator-prey models.

Section C

Mathematical modeling of epidemics: Basic concepts. Simple epidemic model, formulation, solution, interpretation, and limitations. General epidemic model, formulation, solution, interpretation, and limitations

Suggested Text Books:

1. Murray, J. D. (2013). *Mathematical Biology*. Berlin: Springer Berlin.
2. Freedman, H. I. (1987). *Deterministic mathematical models in population ecology*. (2nd Ed.). Edmonton, Alta., Canada: HIFR Consulting.

Suggested Reference Books:

1. Hastings, A. (2010). *Population biology*. New York: Springer.
2. Meerschaert, M. M. (2013). *Mathematical modeling*. (4th Ed.). Amsterdam: Elsevier Academic Press.
3. Meyer, W. J. (1984). *Concepts of mathematical modeling*. New York, N.Y.

4. May, R. (1976). *Theoretical ecology. Principles and applications*. United States.

5. Bailey, N. T. J., & Bailey, N. T. J. (1975). *The mathematical theory of infectious diseases and its applications*. New York: Oxford University Press.

Suggested E-learning material

1. NPTEL: https://nptel.ac.in/courses/102101003/ and https://nptel.ac.in/courses/102101003/#

2. Biomathematics Lectures - UBC Zoology**:** www.zoology.ubc.ca/~bio301/Bio301/Lectures.html

MATH 535 Combinatorial Optimization

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- define the concept of combinatorial (optimisation or satisfaction) problem
- recognize many types of combinatorial optimization problems;
- formulate linear and integer programs, and identify when a problem can be viewed in terms of various "standard" combinatorial optimization problems; understand the mathematical concepts underlying these problems and their solutions;
- solve combinatorial optimization problems using suitable algorithms
- analyze the performance of simple algorithms, understand and interpret computational complexity, and reduce one problem to another.

Section A

Combinatorial algorithms for classic discrete optimization problems: Quick Overview of flow problems- Maximum flow, Minimum Cut, Minimum cost flow, Multi-commodity flow, Matching theory - Matchings and alternating paths-Tutte-Berge formula-Maximum cardinality matchings: Bipartite matching via flow, Edmond's blossom algorithm. Introduction to computational complexity.

Single Source Shortest path algorithms–Bellman Ford algorithm, all pair shortest path algorithms – Floyd Warshall algorithm.

Section B

Algorithmic Perspective to Simplex Method: Introduction to Linear Optimization, Equivalence of optimization and separation, LP Formulation, Geometry of Linear Programs, Theory of Simplex Algorithm, Geometric interpretation of Degeneracy, Avoiding cycles, Methods for obtaining initial Basic Feasible Solutions, Linear Programming formulations of shortest path problem.

Section C

Integer Programing: Integrality gap, Branch and Bound algorithm, Cutting-plane algorithm, Applications of these algorithms on Travelling Salesman Problem

Primal-Dual Algorithms: Interpretation of Dual, Optimality conditions for primal and dual, primal-dual algorithms based on complementary slackness, Primal-dual algorithms for shortest path problem, vertex cover and set cover.

Suggested Text Books:

1. Papadimitriou, C. H., & Steiglitz, K. (2006). *Combinatorial optimization: Algorithms and complexity*. New Delhi: Prentice-Hall of India.
2. Hillier, F. S., & Lieberman, G. J. (1995). *Introduction to mathematical programming; 2nd ed*. New York: McGraw-Hill.
3. Cook, W. J. (2011). *Combinatorial optimization*. New York: Wiley.

Suggested References Books:

1. Lange, K. (2004). *Optimization*. New York: Springer.
2. Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2013). *Linear Programming and Network Flows*. Hoboken: Wiley.
3. Taha, H. A., & Pearson Education. (2017). *Operations research: An introduction*. Harlow: Pearson.
4. Korte, B., & Vygen, J. (2012). *Combinatorial Optimization: Theory and Algorithms*. Berlin, Heidelberg: Springer Berlin Heidelberg.
5. Ahuja, R. K., Magnanti, T. L., & Orlin, J. B. (1993). *Network flows: Theory, algorithms, and applications*. Upper Saddle River, N.J: Prentice-Hall.

Suggested E-learning material

1. Topics in Combinatorial Optimization: Lecture Notes(PDF): https://bit.ly/2MY9MB3
2. Optimization –Introduction(Video Lecture) https://nptel.ac.in/courses/111105039/

MATH 559 Transportation System Analysis

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Use optimal transportation decision-making schemes based on transportation data analysis by establishing, testing and solving transportation models.
- Perform simple statistical analysis on transportation field data, sample estimation and hypothesis testing in transportation system.
- Design suitable sampling and experimental methods for transportation system analysis and realize error sources.

Section A

Introduction of transportation system analysis; characteristics, goal and role of transportation system analysis; applications and methodologies of transportation system analysis; Scope of transportation system analysis; TAF system; Impact of TAF system

Section B

Random variables, applications of probability distributions in transportation system analysis, sample distributions and means in transportation system analysis, Central Limit Theorem, Bayesian Theorem, significance and hypothesis testing in transportation systems. Use of transportation field data and data gathering techniques, sources of errors, considerations of transportation system sample size; experiment design for transportation system demand forecasting and transportation operations analysis.

Section C

Intelligent Transportation System (ITS), components of ITS; Causal Loop Diagramming (CLD) system dynamics approach, conceptualization and development in transportation system policy and scenario analysis; Transportation system scenario generation models and techniques: Delphi technique; Seth Harva model; Multi criteria decision making model.

Suggested Books:

1. Papacostas,C.S. (1987) *Fundamentals of transportation system analysis*, PHI.
2. Cascetta, Ennio. (2012). *Transportation Systems Analysis: Models and Applications*. Springer Verlag.
3. Edwards, J. D., & Institute of Transportation Engineers. (1999). *Transportation planning handbook*. (2nd Ed.). Washington: Institute of Transportation Engineers.
4. Levin, R. I., & Rubin, D. S. (2008). *Statistics for management*. New Delhi: Prentice Hall of India.
5. Walpole, R. E. (2014). *Essentials of probability and statistics for engineers and scientists*. Pearson.

6. Mohapatra, P. K. J., Mandal, P., & Bora, M. C. (1994). *Introduction to system dynamics modelling*. London: Sangam.

7. Roberts, N. (1998). *Introduction to computer simulation: A system dynamics modeling approach*. Portland, Or: Productivity Press.

STAT 527 Stochastic Models

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Acquire skills in handling situations involving more than one random variables.
- Understand to analyze the performance of reliability models.
- Learn how to analyze a network of queues with Poisson arrivals and exponential service requirements.
- Learn how to analyze a network of queues with Poisson arrivals and general service requirements.
- Understand the concept of switching in reliability modeling.

Section A

Review of Stochastic processes, Markov process, Markov chain, Poisson Process. Birth and Death process. Expression for mean and variance of a birth and death process. Introduction of queues, Queueing system. Components of a queueing system, Measures of effectiveness and Notations. Steady state solution of M/M/1 and M/M/1/N Queueing Models and their measures of effectiveness.

Section B

Steady state solution of M/M/C Queueing Models and their measures of effectiveness. The transient solution of M/M/1 and M/M/∞ Queueing models including busy period distribution. Imbedded Markov chain

technique and its use to solve the M/G/1 queueing models. Measures of Effectiveness of M/G/1 queueing model.

Section C

Reliability Models: Concept of reliability, early age failures, wearout failures and chance failures. Derivation of general reliability function failure rate, failure density functions and mean time between failures (MTBF). System reliability evaluation: series system, parallel system, partially redundant system, standby system with perfect switching / imperfect switching. Effect of spare components (identical / non-identical) on the system reliability.

Text/References books:

1. Cox, D. R., & Miller, H. D. (1972). *The theory of stochastic processes*. London: Chapman and Hall.
2. Billinton, R., & Allan, R. N. (2013). *Reliability evaluation of engineering systems: Concepts and techniques*. New Delhi: Springer (India).
3. J. Medhi, J. (1994). *Stochastic processes*. New Age International Publications.
4. Bazovsky, I. (2013). *Reliability Theory and Practice*. Dover Publications.
5. Gross, D., & Harris C.M (2002). *Fundamentals of Queueing Theory*. John Wiley & Sons.
6. Allen, A. O. (2014). *Probability, Statistics, and Queueing Theory with Computer Science Applications*. Academic Press.

Suggested E-learning Resources

1. Introduction to Stochastic Processes and its Applications https://nptel.ac.in/courses/110104024/
2. Statistics e-PG-pathshala: https://epgp.inflibnet.ac.in /ahl.php?csrno=34
3. Reliability Engineering, NPTEL: https://nptel.ac.in/courses /105108128/

STAT 521 Demography

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**4**	**0**	**0**	**4**

Learning Outcomes:

After completion of the course, student will be able to:

- Identify principle sources of demographic data and assess their strengths and weaknesses.
- Discuss the demographic significance of age and sex structures and the implications of variations in age & sex structure.
- Construct and interpret life tables.
- Calculation and interpretation of the principal demographic measures, and standardize these measures for comparison.
- Understand the components of population change, including the effects of changing birth, death and migration rates, and demonstrate their influences on age structure.
- Understand the concept of urbanization on the economic growth of the contrary.
- Estimate and project the population by different methods.
- Understand the concept of stable and stationary population.

Section A

Meaning and scope of demography; Sources of demographic data; Census; Population composition and its basic demographic measures: Ratios, Proportions and Percentages; Population pyramids; Quality of demographic data: Population growth rate; Rates of natural increase; Doubling time; Stochastic models for population growth; Intrinsic growth rate models for population growth and their fitting to population data; Coverage and content errors in demographic data; Balancing equations; Chandrasekharan - Deming formula to check completeness of registration data; Adjustment of age data- use of Whipple, Myer and UN indices; Population transition theory.

Section B

Mortality: Rates and Ratios; Crude and age-specific death rates; Infant mortality rate (IMR); Child death rate (CDR); Under five, neo-natal and post neo-natal mortality rate; Maternal mortality rate and Maternal mortality ratio (MMR); Direct and Indirect Standardization; Factors for decline in mortality in recent past; Life tables and their applications; Increment-decrement life tables; Construction of complete and abridged life tables; Model life table.

Natality: Fecundity and fertility; Measure of fertility: Cohort fertility; Children ever born (CEB); Current family size (CFS); Age specific martial fertility rate; Birth order and parity; Parity progression ratio; Length of generation, Measures of reproduction: Total fertility rate; Gross reproduction rate; Net reproduction rate; Replacement index; General fertility models; Fertility schedules; Differential fertility; Levels and trends of fertility.

Section C

Migration - Concepts and types; Its effect on population growth and pattern; Differentials of migration; Measures of migration: Migration rates; Volume of migration and its estimation; Migration component; Migration streams; Hamilton's rate; Migration models; Concept of international migration; Concept of morbidity and its measures.

Urbanization - Growth and distribution of rural - urban population in developed and developing countries. Nuptiality - Concept and analysis of marital status; Singulate mean age at marriage.

Stationary and Stable population theory; Uses of Lotka's stable population theory in estimation of demographic parameters; Population estimates; Population projections and forecasting; Methods of Inter-censal and Post-censal estimation; Methods of population projection.

Suggested Text Books:

1. Ramkumar, R. (2006). *Technical Demography*. New Age International.
2. Pathak, K.B.& Ram, F. (2019). *Techniques of Demographic Analysis* (2nd. ed.). Himalaya Publishing House.

3. Srinivasan, K., Saxena, P. C., & Kanitkar, T. (1979). *Demographic and Socio-economic Aspects of the Child in India*. Himalaya Publishing House.

Suggested Reference Books:

1. Cox, P. R. (2009). *Demography* (6th. ed.). GBR Cambridge University Press.
2. Sinha, V. C., & Zacharia, E. (1984). *Elements of demography*. Allied Publishers.
3. Bhinde, A. A. & Kanitker, T. (2018). *Principles of Population Studies* (19th. ed.). Himalaya Publishing House.

Suggested E-learning Resources

1. Demographic data; Platform: National Family Health Survey, India http://rchiips.org
2. Population Studies; Platform; e-PG Pathshala https://epgp.inflibnet.ac.in/loaddata.php?action=loadpaperlist1&maincat=453
3. Demography ; Platform: University Library - The University of Adelaide
    a. https://www.adelaide.edu.au/library/
4. Demography; Platform: MITOPENCOURSEWARE https://ocw.mit.edu/index.htm

Reading Electives

MATH 603R Advanced Cryptography

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand digital signatures in detail.
- Understand the concept of signcryption and its security requirements.
- Understand the identity based cryptography.

Digital signatures: Definitions, formal definition of security, relations between security notions, strong unforgeability, one-time signature, signature from one-way function, hash-and-sign paradigm, security of RSA signature, Schnorr signature scheme, Certificates and public key infrastructure.

Signcryption: Definitions, security models for signcryption, signcryption scheme based on Diffie-Hellman Problem.

Identity Based Cryptography: Cocks, Boneh-Franklin, Boneh-Boyen, Sakai-Kasahara identity based encryption schemes.

Suggested Reading:

1. Katz, J. (2010). *Digital signatures*. New York: Springer. (Chapter 1, 3)
2. Katz, J., Lindell, Y.(2015). *Introduction to modern cryptography* (2^{nd} Ed.). Boca Raton: CRC Press. (Chapter 12)
3. Dent, A. W. (2010). *Practical Signcryption*. Berlin: Springer Berlin. (Chapter 2, 3, 4)
4. Martin, L. (2008). *Introduction to identity-based encryption*. Boston: Artech House. (chapter 7, 8, 9, 10)

MATH 604R Advanced Queueing Models

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the principles and objectives of model building based on Markov chains.
- Analyze the queueing situations.
- Understand the mathematical tools that are needed to solve queueing problems.
- Identify and develop queueing models from the verbal description of the real system.
- Understand the various Non-Markovian queueing models.

Time dependent solution of M/M/1 queueing model: Difference equation techniques, Probability generating function techniques, Pegden and Rosenshine technique, Catastrophized M/M/1 queue: Cresenzo et.al technique, Kumar B. K. et.al technique. Steady state solution of M/G/1 and M/G/1/N using supplementary variable technique; GI/M/1, Geo/M/1 using embedded Markov chain technique.

Suggested Reading:

1. Bunday B. D. (1996). *An Introduction to Queueing Theory*, Arnold Publisher.
2. Crescenzo, A. Di et. al. (2003). On the M/M/1 queue with catastrophes and its continuous approximation. *Queuing System*, 43, 329- 347.
3. Conolly B.W. (1957). A difference equation technique applied to the simple queue, *Journal of Royal Statistical Society, Series B*. 20. 165-167.
4. Gross, D., & Harris, C. M. (1985). *Fundamental of Queueing Theory*. (2nd ed.). John Wiley.

5. Takagi, H. (1993). *Queueing Analysis Vol. I, II and III.* Elsevier Sci. Publisher.

6. Kumar B.K. et.al. (2000). Transient solution of an M/M/1 queue with catastrophes. *Computer and mathematics with application.* 40. 1233-1244.

7. Pegden C. D. and Rosenshine. M. (1982). Some new results for the M/M/1 queue, *Management Science.* 28. 821-828.

8. Saaty T. L. (1983). *Elements of Queueing theory with Application.* McGraw Hill, New York .

9. Queuing Systems, NPTEL: https://nptel.ac.in/courses/117103017/1

10. Transient solution of an M/M/1 queue with catastrophe: https://core.ac.uk/download/pdf/81115439.pdf

11. On the M/M/1 queue with catastrophes and its continuous approximation. Source: Queueing Systems journal: https://link.springer.com/article/10.1023/A:1023261830362

12. Some new results for the M/M/1 queue, Source: Management Science journal: https://pubsonline.informs.org/doi/10.1287/mnsc.28.7.821

MATH 605R Algebraic Aspects of Cryptography

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the finite field arithmetic and what are the efficient algorithms for theme
- Know the group law of elliptic curves and able to perform computation on the elliptic curves.
- Grasp the concepts of lattices and their applications in cryptography.

Finite field arithmetic: Introduction to finite fields, Prime field arithmetic, Binary field arithmetic, optimal extension field arithmetic.

Elliptic Curves: Group law, projective coordinate and Jacobian coordinates, Endomorphisms, Torsion points, Divisors and Tate pairings, Supersingular and singular elliptic curves Elliptic curves over finite field, Elliptic Curve Cryptography.

Lattices: Basic definitions and properties, Short vectors in lattices, Babai's Algorithm, NTRU public key cryptosystem, Lattice based digital signature algorithm, Lattice reduction algorithm.

Suggested Reading:

1. Hankerson, D. R., Vanstone, S. A., & Menezes, A. J. (2011). *Guide to elliptic curve cryptography*. New York: Springer. (Chapter 2)
2. Washington, L. C. (2008). *Elliptic Curves, Number Theory and Cryptography*.(2nd Ed.). Taylor & Francis.(Chapter 2, 3, 4, 6).
3. Martin, L.(2008). *Introduction to Identity based Encryption*. Artech House, London. (Chapter 3, 4, 6).
4. Hoffstein, J., Pipher, J. C., & Silverman, J. H. (2014). *An introduction to mathematical cryptography*. New York: Springer. (Chapter 7).

MATH 606R Algebraic Geometry

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- have knowledge of the basic affine and projective geometries.
- Be familiar with explicit examples including plane curves, quadrics, cubic surfaces, Segre and Veronese embedding.

- increased their knowledge of finitely generated commutative rings and their fields of fractions.
- learn how to formulate and prove basic statements about algebraic varieties. precise abstract algebraic language.

Algebraic curves in plane, closed subset of affine space, rational functions, projective and quasi projective varieties, projective spaces, hypersurfaces, product and maps of quasiprojective varieties, Normal varieties.

Dimension and degree, singular and non-singular points, singularities of a map, divisors, divisors on curves, plane cubic, algebraic group, differential forms, Riemann-Roch theorem on curves.

Suggested Readings:

1. Shafarevich , I.R. (1974). *Basic Algebraic Geometry*, Springer-Verlag, Berlin.
2. Robin, H. (1997) *Algebraic Geometry*. New-York: Springer.
3. Schenck .(2003). *Computational Algebraic Geometry*. Cambridge.
4. J. Harris. (1992). *Algebraic Geometry: A First Course*. Springer-Verlag.

Suggested E-learning Resources

1. Basic Algebraic Geometry : Varieties, Morphisms, Local Rings, Function Fields and Nonsingularity, NPTEL course: https://nptel.ac.in/downloads/111106097

MATH 609R Decision and Game Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand and explain the framework of Decision Theory, its intrinsic limitations and broad goals, and how it leads to Game Theory.
- Demonstrate an understanding of games in pure and mixed strategies.
- Explain the game theoretic concepts of uncertainty, information and strategic moves.
- Explain the characteristics and application of repeated games and associated trigger strategies.
- Apply decision making models in interaction situations.
- Gain a proper understanding of game theoretic concepts and modeling: covering equilibrium in static and dynamic games, with varying information structures.

Finite Games, Equilibrium Points, Games with Infinitely many Strategies, Infinite Games, Concave-Convex Games, Multistages Games, Stochastic Games, Two Person General-Sum Games, Bimatrix Games, Non-Atomic Games.

Differential Games, Nash Equilibrium, Identifying Nash Equilibria, Solution of n-persons games with and without zero-sun restriction. Lanchester's equations and their application to games of strategy, Statistical Games, General Techniques for Solving Statistical Games.

Bayesian Decision Theory, Preposterior and Sequential Analysis, Group Decisions and Social Choice, Influence Diagrams, Mulyi Attribute Utiltiy.

Suggested Readings:

1. Owen, G. (2008). *Game theory*. New York: Academic Press.

2. McKinsey, J. C. C. (2012). *Introduction to the Theory of Games*. Newburyport: Dover Publications.
3. Myerson, R. B. (2004). *Game theory: Analysis of conflict*. Cambridge, MA: Harvard University Press.
4. Jorgensen, S., & Zaccour, G. (2004). *Differential games in marketing*. Boston: Kluwer Academic Publishers.
5. Smith, J. Q. (1992). *Decision analysis: A bayesian approach*. London: Chapman & Hall.
6. Lindley, D. V. (2003). *Making decisions*. London: Wiley & Sons.
7. French, S. (1993). *Decision theory: An introduction to the mathematics of rationality*. Chichester: Ellis Horwood.
8. DeGroot, M. H. (2005). *Optimal statistical decisions*. Hoboken, N.J: Wiley-Interscience.
9. Clemen, R. T. (2001). *Making hard decisions with decision tools*. Pacific Grove, CA: Duxbury.

Suggested E-learning Resources

1. Economic Applications of Game Theory (Lecture notes PDF):

   https://ocw.mit.edu/courses/economics/14-12-economic-applications-of-game-theory-fall-2012/index.htm

MATH 612R Finite Element Methods

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand global, local, and natural coordinates.
- Understand the significance of shape functions (linear, quadratic, cubic) in finite element formulations and can formulate one and two-dimensional elements like triangular and rectangular elements.

- Understand the concepts behind variational methods and weighted residual methods in FEM
- be able to implement the Galerkin residual weak formulation into the Finite Element Method for the solution of Ordinary and Partial Differential Equations.

The fundamentals of finite element methods, Discritization of the bounded area, stiffness matrix, assembly of stiffness matrices, Global stiffness matrix.

Shape function: Linear and higher order shape functions for linear, triangular and rectangular elements, Variational Formulation, Rayleigh-Ritz method and Weighted residue method, Galerkin's method

Finite Element formulation for PDE, Laplace equation, wave equation and diffusion equation.

Suggested Readings:

1. Reddy, J. N. (1993). Introduction to the finite element methods (2nd ed.). McGraw-Hill Education.
2. Norrie, D. H., & DeVries. Introduction to finite element methods. New York: Academic Press.
3. Brenner, S. C., & Scott, L. R. (2008). The mathematical theory of finite element methods. New York, NY: Springer -Verlag.
4. Ciarlet, P. G. (2002). The finite element method for elliptic problems. Philadelphia: SIAM.
5. Johnson, C. (1987). Numerical solution of partial differential equations by the finite element methods. Cambridge: Cambridge University Press.
6. Mercier, C. (1979). Lectures on topics in finite element solution of elliptic problems, TIFR Lectures on Mathematics and Physics, Vol. 63, Narosa Publ. House, New Delhi,.

Suggested E-learning Resources

1. PDF of Lectures on Finite Element Method by C. Mercier; Platform: The Tata Institute of Fundamental Research, Bombay 1975: http://www.math.tifr.res.in/~publ/ln/tifr49.pdf

MATH 613R Finite Field Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand finite fields and their extension in detail.
- Find primitive polynomial, factorization of polynomials.
- Understand Gauss, Jacobi, and Kloosterman sums, character sums and their applications.

Introduction to finite fields, extension fields, trace and norm function, bases linearized polynomial, irreducible polynomial, primitive polynomial, factorization of polynomials, normal bases, Completely normal bases, Gauss, Jacobi, and Kloosterman sums, exponential and character sums, Some applications of character sums.

Suggested Reading:

1. Mullen, G. L., & Panario, D. (2013). *Handbook of finite fields*. Boca Raton: CRC Press.
2. Lidl, R., & Niederreiter, H. (2002). *Introduction to finite fields and their applications*. Cambridge: Cambridge University Press.
3. Menezes, A. J. (2011). *Applications of finite fields*. New York: Springer.

MATH 616R Intelligent Transport System

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- understand the sensor and communication technologies.
- differentiate different ITS user services
- define the significance of ITS under Indian conditions
- select appropriate ITS technology depending upon site specific conditions.
- design and implement ITS components

Definition of ITS, historical context of ITS from both public policy and market economic perspectives, Types of ITS; Benefits of ITS.

Importance of telecommunications in the ITS. Information Management, Traffic Management Centers (TMC). Application of sensors to Traffic management; ITS Data collection techniques – Detectors, Automatic Vehicle Location (AVL), Automatic Vehicle Identification (AVI), GIS, video data collection.

ITS User Needs and Services and Functional areas: Introduction, Advanced Traffic Management systems (ATMS), Advanced Traveler Information systems (ATIS), Advanced Vehicle Control systems (AVCS), Advanced Public Transportation systems (APTS), ITS and safety, ITS and security, ITS planning.

ITS applications: Traffic and incident management systems; ITS and sustainable mobility, travel demand management, electronic toll collection, ITS and road-pricing.; public transportation applications; ITS and regional strategic transportation planning, ITS Programs in the World – Overview of ITS implementations in developed countries, ITS in developing countries.

Suggested Readings:

1. Sussman, J. (2010). *Perspectives on Intelligent Transportation Systems (ITS)*. New York: Springer.
2. Mashrur A. C. and Adel W. S.(2003). Fundamentals of Intelligent Transportation Systems Planning, Artech House, Inc., 2003.
3. Lawrence A. Klein, Sensor Technologies and Data requirements of ITS.
4. Kan Paul Chen and John Miles; ITS Hand Book 2000: Recommendations for World Road Association (PIARC).
5. National ITS Architecture Documentation, US Department of Transportation, 2007

Suggested E-learning Resources

1. Benefits of Intelligent Transportation System; Platform: *https://www.its.dot.gov/factsheets/benefits_factsheet.htm*
2. Intelligent Transportation System; Platform NPTEL: https://nptel.ac.in/courses/105101008/48
3. Intelligent Transportation System: https://www.wsp.com/en-US/services/intelligent-transportation-systems-its

MATH 617R Inventory and Production Management

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Demonstrate what inventory is and where we find it within the supply chain.
- Demonstrate the types of demand patterns common in real inventory problems.

- Prepare appropriate inventory planning models for differing demand patterns.
- Recognize the importance of inventory management.
- Understand Production management basics and its history.
- Formulation of aggregate planning problems; their objectives, constraints and applicable solution techniques.
- Understand the terms Trade credit, Inflation, VMI etc. and learn how to use these policies in inventory modeling.

Deterministic Inventory Lot-Size Model with Time proportional demand. Deterministic joint replenishment policy. Inventory Control of deteriorating items (discrete and Continuous). Inventory control under inflationary conditions. Inventory models with stock dependent demand. Interaction of inventory and trade credit policies. Impact with marketing policies on inventory decisions. Joint buyer-seller inventory model. The distribution free newsboy problem and its extensions.

Introduction to VMI and Supply chain. Interaction of Inventory, Queues and Reliability. Aggregate Production Planning Fixed and Variable Work Force Model. Inventory Location Model. Production Planning with Time Varying Demand.

Suggested Readings:

1. Waters, D. (2009). *Inventory control and management*. Chichester: Wiley.
2. Heizer, J., & Render, B. (2001). *Principles of operations management*. Upper Saddle River, N.J: Prentice Hall.
3. Zipkin, P. H. (2000). *Foundations of inventory management*. Boston, MA: McGraw-Hill.
4. Bernard, P. (1999). *Integrated inventory management*. New York: Wiley.
5. Silver, E. A., Pyke, D. F., & Peterson, R. (2006). *Inventory management and production planning and scheduling*. New York: John Wiley & Sons.

6. Wild, T. (2002). *Best practice in inventory management*. Oxford: Butterworth Heinemann.

7. Bedworth, D. D. (1998). *Integrated production control systems*. New York: John Wiley & Sons, Inc. wen jing.

8. Plossl, G. W. (1986). *Production and inventory control: Principles and techniques*. New Delhi: Prentice-Hall.

Suggested E-learning Resources

1. Basic Inventory Principles (PDF): https://nptel.ac.in/ courses/112102106/38

2. Supply Chain Management &Vendor-managed Inventory (PDF):

   https://ocw.mit.edu/courses/sloan-school-of-management/15-760a-operations management-spring-2002/lecture-notes/

MATH 618R Marketing Management

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the concept of marketing and its role in business and public organization.
- Understand the need for scientific marketing analysis.
- To uses Mathematical models in Marketing and understand their limitations.

Consumer Behavior, Contribution of Consumer Behavior in Marketing Management; Market Segmentation; Purchasing Decision with Market price Increase Anticipated; Purchasing under Varying marketing Parameters viz: Price, Quality, Promotional Effort and Distribution Expenses; Promotional and Pricing Decisions under Competition; Planning Suitable Channels of Distribution appropriate to various Classes

of Goods and Customers; Media Planning and Media Allocation Models Determining the Optimal Return on Investment for an Advertising Campaign.

Diffusion of Products with Limited Supply and Known Expiration Date. Diffusion of Innovation under Supply Constraints.

Suggested Readings:

1. Bass, F. M. (1964). *Mathematical models and methods in marketing*. Homewood, Ill: Irwin.
2. Kotler, P., & Keller, K. L. (2016). *A framework for marketing management*. Upper Saddle River, New Jersey: Pearson Education Inc.
3. Lilien, G. L., Kotler, P., & Moorthy, K. S. (2009). *Marketing models*. Prentice Hall of India.
4. King, W. R. (1967). *Quantitative analysis for marketing management*. New York: McGraw-Hill.

MATH 621R Numerical Solutions of Partial Differential Equations

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Solve mathematical models represented by initial or boundary value problems involving partial differential equations that cannot be solved directly using standard mathematical techniques but are amenable to a computational approach.
- Select appropriate numerical methods based on the characteristics of a PDE problem.

- Introduce the discretization methodologies, with particular emphasis on the finite difference method that allows the construction of accurate and stable numerical schemes.
- Discuss about the stability and convergence of the numerical methods.

Numerical solutions of parabolic PDE in one space: two and three levels explicit and implicit difference scheme. Numerical solution of parabolic PDE of second order in two dimensional space implicit methods, alternating direction implicit (ADI) methods, Non-linear initial BVP.

Difference schemes for parabolic PDE in spherical and cylindrical coordinate systems in one dimension. Numerical solution of hyperbolic PDE in one and two space dimension: explicit and implicit schemes. Lax's equivalence theorem, Finite difference schemes for initial and boundary value problems - FTCS, backward Euler and Crank-Nicolson schemes, Difference schemes for first order equations.

Numerical solutions of elliptic equations, approximations of Laplace and biharmonic operators. Solutions of Dirichlet, Neuman and mixed type problems.

Suggested Readings:

1. Jain, M. K., Iyenger, S. R. K., & Jain, R. K. (1994). Computational methods for partial differential equations. Willey Eastern.
2. Jain, M. K. Numerical solution of differential equations (2nd ed.). Wiley Eastern.
3. Sastry, S. S. (2002). Introductory methods of numerical analysis, Prentice-Hall of India.
4. Griffiths, D. V., & Smith, I. M. (1993). Numerical methods of engineers, Oxford University Press.
5. General, C. F., & Wheatley, P. O. (1998). Applied numerical analysis, Addison-Wesley.
6. Smith, G. D. (1986). Numerical solutions to partial differential equations (3rd ed.). Oxford University Press.

Suggested E-learning Resources

1. Lecture notes on Numerical Methods for Partial Differential Equations; Platform: MIT open course ware;

   https://ocw.mit.edu/courses/aeronautics-and-astronautics/16-920j-numerical-methods-for-partial-differential-equations-sma-5212-spring-2003/lecture-notes/

2. Lecture notes on Numerical Solution of Partial Differential Equations; Platform: nptel; https://nptel.ac.in/courses /111107063/21

MATH 622R Operator Theory

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Tell what is operators
- Define several standard examples of linear operators, self-adjoint operators and prove simple results related to them.
- Spectral representation of compact self-adjoint operators in Hilbert spaces.
- Applications of spectral Theorem for compact operators.
- Some recent results and open problems in operator theory

Dual space considerations: Representation of duals of the spaces with p-norms, and c with supremum-norm, C[a,b] and . Reflexivity, Weak and weak* convergences. Best Approximation in Reflexive spaces.

Operators on Banach and Hilbert spaces: Compact operators and its properties; Integral operators as compact operators; Adjoint of operators between Hilbert spaces; Self-adjoint, Normal and unitary operators; Numerical range and numerical radius; Hilbert--Schmidt operators.

Spectral results for Banach and Hilbert space operators: Eigen spectrum, Approximate eigen spectrum, Spectrum and resolvent; Spectral radius formula, Spectral mapping theorem; Riesz-Schauder theory, Spectral results for normal, Self-adjoint and unitary operators; Functions of self-adjoint operators.

Suggested Readings:

1. Nair, M. T. (2008). *Functional analysis: A first course* (6th Ed.). New Delhi: Prentice Hall of India.
2. B.V. Limaye(2014). *Functional Analysis*(3th. ed.). New Age Internationals.
3. Conway, J. B. (2013). *A course in functional analysis* (Vol. 96). Springer Science & Business Media.
4. Goffman, C., & Pedrick, G. (2017). *A first course in functional analysis* (Vol. 319). American Mathematical Soc.
5. Gohberg, I., & Goldberg, S. (2013). *Basic operator theory*. Birkhauser.
6. Kreyzig E. (1989) . *Introduction to Functional Analysis with Applications*. Wiley
7. Bachman, G. & Narici L. (1964). *Functional analysis*. Academic Press.

MATH 624R Special Functions

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- understand various types of special functions, and their conditions of existence.
- carry out relations between different special functions, including some of the most useful special functions.

- demonstrate understanding of the concepts of recurrence relations, generating functions, series representations pertaining to different special functions and polynomials.
- determine some significant properties of special functions and their integral forms.
- discuss the nature of various special functions in different domains.

The Gamma and Beta Functions: Eulers' integral for$\Gamma(z)$, the beta function, factorial function, Legendre's duplication formula, Gauss's multiplication theorem, summation formula due to Euler, behavior of log $\Gamma(z)$ for large $|z|$. The Hypergeometric function: An integral representation, differential equation and solutions. F(a,b,c;1) as a function of the parameters, evaluation of F(a,b,c;1), contiguous function relations

The hypergeometric differential equation, logarithmic solutions of the hypergeometric equation, F(a,b,c;z) as a function of its parameters, Elementary series manipulations, simple transformations, relation between functions of $\Gamma(z)$ and, $\Gamma(1-z)$ quadratric transformations, theorem due to Kummer, additional properties. The Confluent Hypergeometric function: Basic properties of 1F1, Kummer's first formula. Kummer's second formula, Generalized Hypergeometric Series: The function pFq, the exponential and binomial functions, differential equation, contiguous function relations, integral representation pFq, with unit argument, Saalshutz' theorem, Whipple's theorem, Dixon's theorem, Contour integrals of Barnes' type.

Bessel Functions: Definition, Differential equation, differential recurrence relations, pure recurrence relation, generating function, Bessel's Integral, index half an odd integer, modified Bessel functions,

Introduction to Legendre function, Meijer G-function and some basic properties, Fox's H-Function.

Suggested Readings:

1. Ranvillie, E.D. (1960). *Special Functions*. Macmillan.

2. Andrews, L. C. (1992). *Special Functions of Mathematics for Engineers*. SPIE Press.

3. Szego, G. (1939). *Orthogonal Polynomials*. American mathematical society.

4. Slater, L.J. (2008). *Generalized Hypergeometric Functions*. Cambridge University Press.

5. Mathai, A. M. & Haubold H. J. (2008). *Special Functions for Applied Scientists*. Springer.

Suggested E-learning Resources

1. Special Functions and Their Symmetries: www1.maths. leeds.ac.uk/~kisilv/courses/special.html

STAT 602R Advanced Reliability Theory

	L	T	P	C
Max. Marks : 100				
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Estimate the reliability function and mean time to failure for different types of systems.
- Understand major concepts of reliability prediction.
- Analyze statistical experiments leading to reliability modeling.
- Estimate life length distributions, using complete or censored data.
- Identify reliability testing components.
- Apply reliability theory to assessment of reliability in engineering design.
- Know Bayesian reliability concept.
- Determine Life table and Kaplan- Meier approach.
- Understand MCMC technique for simulation.

Concept of Reliability: Definition of reliability and its measures, Importance of reliability, Concept of failure, Fault tree analysis.

Lifetime Models: Notion of aging, concept of hazard rate for life time distributions (exponential, Weibull, Log-Normal, Gamma, Inverse Gaussian) , Increasing failure rate (IFR) and Decreasing failure rate (DFR) class of life distributions, Bath-tub failure curve.

Life Testing and inference: Life testing, Complete data and censored data, Type-I, Type-II, hybrid and random censoring schemes. Parametric inference based on complete and censored data, Nonparametric estimate (Life table and Kaplan-Meier) of reliability, Graphical methods (PP, QQ and TTT plots) and standard statistical tests for model validation.

Bayesian Reliability: Bayesian approximations and Reliability estimation, Bayesian intervals for parameters and Reliability functions.

Suggested Readings:

1. Sinha, S. K. (1986). *Reliability and life testing*. John Wiley & Sons, Inc..
2. Nelson, W. B. (2005). *Applied life data analysis* (Vol. 577). John Wiley & Sons.
3. Meeker, W. Q., & Escobar, L. A. (2014). *Statistical methods for reliability data*. John Wiley & Sons.
4. Deshpande, J. V., & Purohit, S. G. (2006). *Lifetime Data: Statistical Models and Methods* (Vol. 11). World Scientific Publishing Company.
5. Lawless, J. F. (2011). *Statistical models and methods for lifetime data* (Vol. 362). John Wiley & Sons.
7. 6. Kapur, K. C., & Lamberson, L. R. (1977). *Reliability in engineering design*. New York: Wiley.
9. Høyland, A., & Rausand, M. (2009). *System reliability theory: models and statistical methods* (Vol. 420). John Wiley & Sons.
10. Barlow, R. E., & Proschan, F. (1996). *Mathematical theory of reliability* (Vol. 17). John Wiley, New York..

11. Barlow, R. E., & Proschan, F. (1975). *Statistical theory of reliability and life testing: probability models*. Rinehart and Winston, New York..

Suggested E-learning Resources

1. Reliability Theory, Platform: NPTEL https://nptel.ac.in/courses/114106041/15.
2. MLE and Bayesian Estimation-1, Platform: NPTEL https://nptel.ac.in/courses/pdf_link/103106123/lec109.pdf
3. Module, Sysytems and Reliability; Platform: MIT Open Course ware: https://ocw.mit.edu/courses/mechanical-engineering/2-627-fundamentals-of-photovoltaics-fall-2013/lecture-videos-slides/2011-lecture-17-modules-systems-and-reliability/

STAT 604R Biostatistics

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand various measures in medical studies.
- Assess validity and reliability of a test.
- Find association and causal relations between the variables.

Measuring the occurrence of disease: Measures of morbidity - prevalence and incidence rate, association between prevalence and incidence, uses of prevalence and incidence, problems with incidence and prevalence measurements; Clinical agreement: kappa statistics, intra-class correlation; Surveillance;

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

Issues in epidemiology: Association; causation; causal inference; Errors and bias; Confounding; Controlling confounding; Measurement of interactions; Generalizability;

Odds ratios for retrospective studies; Odds ratios approximating the prospective RR; Exact inference for odds ratio analysis of matched case-control data.

Suggested Readings:

1. Altman, D. G. (1990). *Practical statistics for medical research*. CRC press.
2. Rosner, B., & Cengage Learning. (2017). *Fundamentals of biostatistics* (6th. Ed.). Boston: Cengage Learning.

STAT 608R Generalized Linear Models

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the concept of logistic regression, its estimation and testing.
- Understand the procedure to regression analysis for dependent count variable using Poisson regression.
- Broaden their understanding of regression model to generalized linear models and their application.

Logistic Regression: Logit transform. ML estimation. Tests of hypotheses, Wald test, LR test, score test, test for overall regression, multiple logistic regression, forward, backward method, interpretation of parameters, relation with categorical data analysis.

Poisson Regression: Introduction to Poisson regression, MLE for Poisson regression, Applications in Poisson regressions.

Family of Generalized Linear Models: Exponential family of distributions, Formal structure for the class of GLMs, Likelihood equations, Quasi likelihood, Link functions, Important distributions for GLMs, Power class link function.

Suggested Readings:

1. Christensen, R. (1997). *Log-linear Models and Logistic Regression* (2nd. Ed.) Springer.
2. Dobson, A.J. and Barnett, A.G. (2008). *Introduction to Generalized Linear Models*(3ed ed.). Chapman and Hall/CRC. London.
3. Hastie, T.J. and Tibshirani, R.J. (1990). *Generalized Additive Models*. (2nd. ed.). Chapman and Hall, New York.
4. Hosmer, D.W. and Lemeshow, S. (2000). *Applied Logistic Regression* (2nd ed.). Wiley, New York.
5. Lindsey, J. K. (1997). *Applying generalized linear models*. Springer-Verlag, New York.
6. McCullagh, P. and Nelder, J.A. (1989). *Generalized Linear Models*(2nd. ed.). Chapman and Hall.
7. McCulloch, C.E. and Searle, S.R. (2001). *Generalized, Linear and Mixed Models*. John

   Wiley & Sons, Inc. New York.
8. Myers, R.H., Montgomery, D.C and Vining, G.G. (2002). *Generalized Linear Models with Applications in Engineering and the Sciences*. John Wiley & Sons.

STAT 610R Statistical Computing

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Simulate and generate statistical data by different techniques.
- Estimate the unknown parameter of population via different methods.
- Understand the basic concepts of statistical theories besides developing their ability to handle real world problems with large scale data.

Random numbers, Pseudo random number generation: Inverse transform method, Acceptance-rejection, Transformations. Tests for randomness. Multivariate probability calculation, Simulation and Monte Carlo integration, Variance reduction, Importance sampling.

Markov-Chain Monte Carlo: Metropolis-Hastings algorithm, Gibbs sampling, Jack-knife method, Bootstrap method, Bootstrap confidence intervals, Likelihood estimation, Bootstrap of dependent data.

Density estimation: Univariate and Multivariate estimation, Bayesian posterior density estimation, EM algorithm.

Suggested Reading:

1. Givens, G. H. and Hoeting, J.A. (2013). *Computational Statistics* (2nd. Ed.). Wiley.
2. Law, A. M., Kelton, W. D., & Kelton, W. D. (1991). *Simulation modeling and analysis* (Vol. 2). Tata McGraw-Hill.
3. Thisted, R. A.(1988). *Elements of Statistical Computing.* Chapman and Hall.
4. Robert, C. P, & Casella, G. (2010). *Introducing Monte Carlo methods with R*. Springer Verlag.

Suggested E-learning Resources

1. Statistical computing Platform: MITOPENCOURSEWARE https://ocw.mit.edu/index.htm
2. Statistics: Platform: e-PG Pathshala https://epgp.inflibnet.ac.in

STAT 611R Supply Chain Management

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Understand the structure of supply chains and the different ways through which supply chains can become competitive in the realistic problems.
- Understand fundamental supply chain management concepts.
- Apply knowledge to evaluate and manage an effective supply chain.
- How to align the management of a supply chain with corporate goals and strategies.
- Analyze and improve supply chain processes.
- Identify the principles of customer and supplier relationship management in supply chains.

Building Blocks of a Supply Chain Network, Business Process in Supply Chains, Types of Supply Chains and Examples, Strategic, Tactical, and Operational Decisions in Supply Chains, Supply Chain Performance Measures.

Supply Chain Inventory Management: Newsboy, Base-stock, and (Q,r) Models, Multi-Echelon Supply Chains, Performance of Supply Chains using Markov Chains and Queueing Networks.

Mathematical Programming Models for Supply Chain Planning, Design and Optimization, Internet- Enabled Supply Chains ERP and Supply Chains, Customer Relationship Management.

Suggested Readings:

1. Chopra, S., & Meindl, P. (2007). *Supply chain management: Strategy, planning, and operation*. Upper Saddle River, N.J: Pearson Prentice Hall.
2. Shapiro, J. F. (2007). *Modeling the supply chain*. Australia: Thomson Brooks/Cole.

3. Viswanadham, N. (2000). *Analysis of manufacturing enterprises: An approach to leveraging value delivery processes for competitive advantage*. Boston: Kluwer Academic.

4. Ganeshan, R., Magazine, M. J., & Tayur, S. R. (2003). *Quantitative models for supply chain management*. Boston, Mass: Kluwer Acad.

5. Handfield, R. B. (2012). *Introduction to Supply Chain Management*. Pearson Education.

6. Viswanadham, N., & Narahari, Y. (2005). *Performance modeling of automated manufacturing systems*. New Delhi: Prentice-Hall of India.

Suggested E-learning Resources

1. Introduction to Supply chain management (PDF): https://nptel.ac.in/courses/110106045/35

STAT 612R Survival Analysis

Max. Marks : 100	**L**	**T**	**P**	**C**
(ESA: 100)	**0**	**0**	**0**	**2**

Learning Outcomes:

After completion of the course, student will be able to:

- Identify characteristics of survival data and problems in their correct analysis
- Define and understand the relationship between the survival function, distribution function,
- Hazard function, relative hazard, and cumulative hazard
- Perform and interpret analyses of survival data using common statistical procedures
- Fit the proportional hazards regression model to survival data and assess the scientific
- significance, precision, and interpretation of regression coefficients
- Fit parametric regression model to survival data and assess the scientific significance,
- precision, and interpretation of regression coefficients

- Use graphical and other methods to assess the adequacy of fitted models and propose
- Alternate solutions when common assumptions are violated
- Use time-dependent covariates in the proportional hazards model and interpret the coefficients

Concepts of time, order and random censoring. Life distributions - exponential gamma, Lognormal, Pareto, linear failure rate. Life tables, failure rate, mean residual life and their elementary properties. Ageing classes - IFR, IFRA, NBU, NBUE, HNBUE and their duals, Bathtub failure rate.

Estimation of survival function - Actuarial estimator, Kaplan - Meier estimator. Estimation under the assumption of IFR/DFR.

Semi-parametric regression for failure rate - Cox's proportional hazards model. Competing risk models. Repair models. Probabilistic models. Joint distribution of failure times. Unconditional tests for the time truncated case. Tests for exponentiality, two sample non-parametric problem.

Suggested Readings:

1. Collet, D. (2003). *Modeling Survival Data in Medical Research*. London: Chapman and Hall.
2. Hosmer, D. and Lemeshow S. (1999). *Applied Survival Analysis: Regression Modeling of Time to Event Data.* New York: Wiley.
3. Breslow, N. and Day, N. (1987). *Statistical Methods in Cancer Research*: *The Design and Analysis of Cohort Studies*. Lyon: IARC.
4. Therneau T, and Grambsch, P. (2000). *Modeling Survival Data: Extending the Cox Model*. New York: Springer
5. Kalbfleish, JD. and Prentice, RL. (2002). *The Statistical Analysis of Failure Time Data.* New York: Wiley.

Suggested E-learning Resources

1. http://www.stat.columbia.edu/~madigan/W2025/notes/survival.pdf