BANASTHALI VIDYAPITH

M.Sc. (Mathematical Science)

Curriculum Structure

First Semester Examination, December, 2019
Second Semester Examination, April/May, 2020
Third Semester Examination, December, 2020
Fourth Semester Examination, April/May, 2021

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

July, 2019

105

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.

M.Sc. (Mathematical Science)

Programme Educational Objectives

Banasthali's education ideology is to nurture women leaders in all walks of life with strong value base. Mathematical Sciencesis the most important discipline in today's world which open doors in engineering, business, finance, computing, data science, health sciences and environmental sciences. The educational objective of the M.Sc. Mathematical Sciencesprogramme is to provide high quality education in mathematics, statistics, operations research and theoretical computer science 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 define mathematical concepts, calculate quantities, estimate solutions, design data collection, analyze data appropriately and interpret to draw conclusions from these data. It emphasizes on both theory and applications of mathematics and statistics and is structured to provide knowledge and skills in depth necessary for the employability of students in industry, other organizations, as well as in academics.

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

- To develop an understanding of the mathematics, statistics, operations research and theoretical computer science as a unifying language of science.
- To use mathematical and statistical techniques to solve well-defined real-world problems and understand the limitations.
- To provide exposure to various mathematical and statistical software packages, including analysis and programming.
- To develop communication and technical writing skills which enables them 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 the basic concepts in mathematics, statistics, operations research and theoretical computer science and their importance in the solution of some real-world problems.

PO2: **Problem Analysis:**Analyze and solve the well-defined problems in mathematics statistics, operations research and theoretical computer science. 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

M.Sc.

(Mathematical Science-Pure Mathematics)

Semester - I

Course	Code	Course Name	L	T	P	C *
CS	415	Computer Programming	4	0	0	4
CS	415L	Computer Programming Lab	0	0	4	2
MATH	412	Algebra - I	5	0	0	5
MATH	415	Analysis - I	5	0	0	5
MATH	420	Discrete Mathematics	4	0	0	4
STAT	402	Probability and Statistics	4	0	0	4
MATH	417L	Computational Lab-I	0	0	4	2
		Semester Total :	**22**	**0**	**8**	**26**

Semester - II

Course	Code	Course Name	L	T	P	C *
MATH	413	Algebra - II	5	0	0	5
MATH	416	Analysis - II	5	0	0	5
MATH	409	Numerical Analysis	4	0	0	4
MATH	409L	Numerical Analysis Lab	0	0	4	2
MATH	422	Ordinary Differential Equations	4	0	0	4
MATH	423	Topology	4	0	0	4
MATH	418L	Computational Lab-II	0	0	4	2
		Semester Total :	**22**	**0**	**8**	**26**

Semester - III

Course	Code	Course Name	L	T	P	C *
MATH	531	Advanced Calculus	4	0	0	4
MATH	542	Functional Analysis	4	0	0	4
MATH	550	Operations Research	4	0	0	4
MATH	528P	Term Paper	0	0	8	4
		Discipline Elective - I	4	0	0	4
		Discipline Elective - II	4	0	0	4
		Reading Elective-I	0	0	0	2
		Semester Total :	**20**	**0**	**8**	**26**

Semester - IV

Course	Code	Course Name	L	T	P	C *
MATH	537	Differential Geometry	4	0	0	4
MATH	551	Partial Differential Equations	4	0	0	4
MATH	538D	Dissertation	0	0	16	8
		Discipline Elective - III	4	0	0	4
		Open Elective	4	0	0	4
		Reading Elective-II	0	0	0	2
		Semester Total :	**16**	**0**	**16**	**26**

Discipline Elective

Course	Code	Course Name	L	T	P	C*
CS	315	Theory of Computation	4	0	0	4
CS	528	Modeling and Simulation	4	0	0	4
ELE	304	Digital Signal Processing	4	0	0	4
MATH	501	Advanced Analysis (Analysis on abstract spaces)	4	0	0	4
MATH	503	Advanced Functional Analysis	4	0	0	4
MATH	504	Analytic and Algebraic Number Theory	4	0	0	4
MATH	543	Fuzzy Logic and Belief Theory	4	0	0	4
MATH	510	Integral equations and Calculus of Variations	4	0	0	4
MATH	546	Inventory Theory	4	0	0	4
MATH	517	Number Theory and Cryptography	4	0	0	4
MATH	555	Queueing Theory	4	0	0	4
MATH	527	Tensor Analysis and Geometry of Manifolds	4	0	0	4
MATH	529	Theory of Games	4	0	0	4
MATH	530	Viscous Fluid Dynamics	4	0	0	4
STAT	406	Measure Theory and Advanced Probability	4	0	0	4
STAT	529	Time Series and Stochastic Process	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	532	Algebraic Topology	4	0	0	4
MATH	535	Combinatorial Optimization	4	0	0	4
MATH	559	Transportation System Analysis	4	0	0	4
MATH	544	Integral Transform and Special Functions	4	0	0	4
MATH	539	Fields and Galois Theory	4	0	0	4

Reading Elective

Course	Code	Course Name	L	T	P	C*
MATH	547R	Network Biology	0	0	0	2
MATH	541R	Fractional Calculus	0	0	0	2
MATH	554R	Quantum Graphs	0	0	0	2
MATH	552R	Point Set Topology	0	0	0	2
MATH	549R	Operational Research Applications	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

Student can opt open (Generic) elective from any discipline of the Vidyapith with prior permission of respective heads and time table permitting.

Every Student shall also opt for:

Five Fold Education: Physical Education I, Physical Education II, Five Fold Education: Aesthetic Education I, Aesthetic Education II, Five Fold Education: Practical Education I, Practical Education II one each semester

Curriculum Structure
M.Sc.
(Mathematical Science- Statistics)

Semester - I

Course	Code	Course Name	L	T	P	C *
CS	415	Computer Programming	4	0	0	4
CS	415L	Computer Programming Lab	0	0	4	2
MATH	412	Algebra - I	5	0	0	5
MATH	415	Analysis - I	5	0	0	5
MATH	420	Discrete Mathematics	4	0	0	4
STAT	402	Probability and Statistics	4	0	0	4
MATH	417L	Computational Lab-I	0	0	4	2
		Semester Total :	**22**	**0**	**8**	**26**

Semester - II

Course	Code	Course Name	L	T	P	C *
CS	417	Database Management Systems	4	0	0	4
CS	417L	Database Management Systems Lab	0	0	4	2
MATH	416	Analysis-II	5	0	0	5
MATH	409	Numerical Analysis	4	0	0	4
MATH	409L	Numerical Analysis Lab	0	0	4	2
STAT	406	Measure Theory and Advanced Probability	4	0	0	4
STAT	407	Statistical Inference	5	0	0	5
		Semester Total :	**22**	**0**	**8**	**26**

Semester - III

Course	Code	Course Name	L	T	P	C *
STAT	532	Survey Sampling	4	0	0	4
STAT	507	Design of Experiments and Linear Models	4	0	0	4
STAT	529	Time Series and Stochastic Process	4	0	0	4
MATH	536L	Computational Lab – III	0	0	4	2
STAT	514S	Seminar	0	0	4	2
		DisciplineElective - I	4	0	0	4
		DisciplineElective - II	4	0	0	4
		Reading Elective – I	0	0	0	2
		Semester Total:	**22**	**0**	**8**	**26**

Semester - IV

Course	Code	Course Name	L	T	P	C *
STAT	519	Advanced Inference	4	0	0	4
STAT	502	Bayesian and Multivariate Analysis	4	0	0	4
STAT	502L	Bayesian and Multivariate Analysis Lab	0	0	4	2
STAT	523P	Project	0	0	12	6
		DisciplineElective - III	4	0	0	4
		Open Elective	4	0	0	4
		Reading Elective – II	0	0	0	2
		Semester Total :	**16**	**0**	**16**	**26**

DisciplineElective

Course	Code	Course Name	L	T	P	C
CS	523	Emerging Programming Paradigms	4	0	0	4
CS	528	Modeling and Simulation	4	0	0	4
MATH	546	Inventory Theory	4	0	0	4
MATH	516	Network Analysis and Goal Programming	4	0	0	4
MATH	555	Queueing Theory	4	0	0	4
MATH	529	Theory of Games	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	515	Statistical Computing	4	0	0	4
STAT	527	Stochastic Models	4	0	0	4
STAT	521	Demography	4	0	0	4
STAT	518	Actuarial Statistics	4	0	0	4
STAT	528	Survival Analysis	4	0	0	4
STAT	524	Reliability and Renewal Theory	4	0	0	4
MATH	550	Operations Research	4	0	0	4

Reading Elective

Course	Code	Course Name	L	T	P	C
STAT	526R	Step-Stress Modelling	0	0	0	2
STAT	520R	Categorical Data Analysis	0	0	0	2
STAT	530R	Official Statistics	0	0	0	2
STAT	531R	Robust Estimation in Non-linear Models	0	0	0	2
MATH	549R	Operational Research Applications	0	0	0	2

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Five Fold Education: Physical Education I, Physical Education II, Five Fold Education: Aesthetic Education I, Aesthetic Education II, Five Fold Education: Practical Education I, Practical Education II one each semester

Curriculum Structure

M.Sc.

(Mathematical Sciences- Operations Research)

Semester - I

Course	Code	Course Name	L	T	P	C *
CS	415	Computer Programming	4	0	0	4
CS	415L	Computer Programming Lab	0	0	4	2
MATH	412	Algebra - I	5	0	0	5
MATH	415	Analysis - I	5	0	0	5
MATH	420	Discrete Mathematics	4	0	0	4
STAT	402	Probability and Statistics	4	0	0	4
MATH	417L	Computational Lab-I	0	0	4	2
		Semester Total :	**22**	**0**	**8**	**26**

Semester - II

Course	Code	Course Name	L	T	P	C *
CS	417	Database Management Systems	4	0	0	4
CS	417L	Database Management Systems Lab	0	0	4	2
MATH	413	Algebra - II	5	0	0	5
MATH	416	Analysis - II	5	0	0	5
MATH	422	Ordinary Differential Equations	4	0	0	4
MATH	409	Numerical Analysis	4	0	0	4
MATH	409L	Numerical Analysis Lab	0	0	4	2
		Semester Total :	**22**	**0**	**8**	**26**

Semester - III

Course	Code	Course Name	L	T	P	C *
CS	209	Data Structures	4	0	0	4
CS	209L	Data Structures Lab	0	0	4	2
MATH	555	Queueing Theory	4	0	0	4
MATH	546	Inventory Theory	4	0	0	4
MATH	525S	Seminar	0	0	4	2
		DisciplineElective - I	4	0	0	4
		DisciplineElective - II	4	0	0	4
		Reading Elective – I	0	0	0	2
	Semester Total :		**20**	**0**	**8**	**26**

Semester - IV

Course	Code	Course Name	L	T	P	C *
STAT	524	Reliability and Renewal Theory	4	0	0	4
MATH	516	Network Analysis and Goal Programming	4	0	0	4
MATH	516L	Network Analysis and Goal Programming Lab	0	0	4	2
MATH	553P	Project	0	0	12	6
		DisciplineElective - III	4	0	0	4
		OpenElective	4	0	0	4
		Reading Elective – II	0	0	0	2
		Semester Total :	**16**	**0**	**16**	**26**

DisciplineElective

Course	Code	Course Name	L	T	P	C*
CS	523	Emerging Programming Paradigms	4	0	0	4
CS	528	Modeling and Simulation	4	0	0	4
MATH	507	Financial Mathematics	4	0	0	4
MATH	513	Marketing Management	4	0	0	4
MATH	529	Theory of Games	4	0	0	4
STAT	406	Measure Theory and Advanced Probability	4	0	0	4
STAT	505	Decision Theory	4	0	0	4
STAT	522	Econometric Models	4	0	0	4
STAT	529	Time Series and Stochastic Process	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
MATH	543	Fuzzy Logic and Belief Theory	4	0	0	4
MATH	551	Partial Differential Equations	4	0	0	4

Reading Elective

Course	Code	Course Name	L	T	P	C*
STAT	526R	Step-Stress Modelling	0	0	0	2
STAT	520R	Categorical Data Analysis	0	0	0	2
STAT	525R	Selected Applications of Stochastic Models	0	0	0	2
MATH	549R	Operational Research Applications	0	0	0	2

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Curriculum Structure

M.Sc.

(Mathematical Sciences-Theoretical Computer Science)

Semester - I

Course	Code	Course Name	L	T	P	C *
CS	415	Computer Programming	4	0	0	4
CS	415L	Computer Programming Lab	0	0	4	2
MATH	412	Algebra - I	5	0	0	5
MATH	415	Analysis - I	5	0	0	5
MATH	420	Discrete Mathematics	4	0	0	4
STAT	402	Probability and Statistics	4	0	0	4
MATH	417L	Computational Lab-I	0	0	4	2
		Semester Total :	**22**	**0**	**8**	**26**

Semester - II

Course	Code	Course Name	L	T	P	C *
CS	417	Database Management Systems	4	0	0	4
CS	417L	Database Management Systems Lab	0	0	4	2
MATH	413	Algebra - II	5	0	0	5
MATH	416	Analysis - II	5	0	0	5
MATH	422	Ordinary Differential Equations	4	0	0	4
MATH	409	Numerical Analysis	4	0	0	4
MATH	409L	Numerical Analysis Lab	0	0	4	2
		Semester Total :	**22**	**0**	**8**	**26**

Semester - III

Course	Code	Course Name	L	T	P	C *
CS	209	Data Structures	4	0	0	4
CS	209L	Data Structures Lab	0	0	4	2
CS	308	Operating Systems	4	0	0	4
CS	315	Theory of Computation	4	0	0	4
CS	528	Modeling and Simulation	4	0	0	4
MATH	526S	Seminar	0	0	4	2
		Discipline Elective - I	4	0	0	4
		Reading Elective – I	0	0	0	2
		Semester Total :	**20**	**0**	**8**	**26**

Semester - IV

Course	Code	Course Name	L	T	P	C *
CS	213	Design and Analysis of Algorithms	4	0	0	4
CS	213L	Design and Analysis of Algorithms Lab	0	0	4	2
CS	313	Software Engineering	4	0	0	4
MATH	553P	Project	0	0	12	6
		Discipline Elective - II	4	0	0	4
		Open Elective	4	0	0	4
		Reading Elective – II	0	0	0	2
		Semester Total :	**16**	**0**	**16**	**26**

DisciplineElective

Course	Code	Course Name	L	T	P	C*
CS	419	Distributed Computing	4	0	0	4
CS	427	Parallel Computing	4	0	0	4
CS	431	Real Time Systems	4	0	0	4
CS	433	Soft Computing	4	0	0	4
CS	507	Artificial Intelligence	4	0	0	4
CS	510	Client - Server Computing and Applications	4	0	0	4
CS	527	Mobile Computing	4	0	0	4
ELE	304	Digital Signal Processing	4	0	0	4
MATH	529	Theory of Games	4	0	0	4
STAT	406	Measure Theory & Advanced Probability	4	0	0	4
STAT	529	Time Series and Stochastic Process	4	0	0	4

Reading Elective

Course	Code	Course Name	L	T	P	C*
MATH	547R	Network Biology	0	0	0	2
MATH	541R	Fractional Calculus	0	0	0	2
MATH	554R	Quantum Graphs	0	0	0	2
MATH	549R	Operational Research Applications	0	0	0	2
STAT	520R	Categorical Data Analysis	0	0	0	2

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

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	7.50andabove
FirstDivision	6.00to 7.49
SecondDivision	5.00to 5.99
Pass	4.00to4.99

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

MATH 412Algebra-I

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**5**	**0**	**0**	**5**

Learning Outcomes:

After completing the course, students will be able to

1. Analyze finite and infinite dimensional vector spaces and subspaces over a field and their properties, including the basis structure of vector spaces.
2. Understand the properties of linear transformations, matrices of linear transformations and change of basis, including kernel, range and isomorphism.
3. Compute inner products and determine orthogonality on vector spaces, including Gram-Schmidt orthogonalization.
4. Identify operators in inner product spaces.
5. Identify bilinear forms, canonical forms for symmetric and skew-symmetric forms.

Section A

Vector spaces, subspaces, linear span,bases,quotient spaces, coordinate vectors, change of basis, linear transformations, isomorphism, range and kernel of a linear transformation, matrix of a linear transformation, algebra of L(U, V), invertible transformations and matrices, Linear functionals and dual spaces**.**

Section B

Linear operator, annihilating polynomials, invariant subspaces of linear operator, direct sum decomposition, cyclic operator, maximal vector, indecomposable linear operators, invariant factors, canonical forms, operators on real and complex vector spaces.

Section C

Inner Product Spaces, Orthonormal Sets, Gram–Schmidt Process, Orthogonal Complements and Projections, Adjoints, self-adjoints and normal operators, unitary and orthogonal operators, Forms on inner product spaces, Bilinear forms, symmetric bilinear forms and quadratic form.

SuggestedBooks:

1. Hoffman, K., & Kunze, R. A. (2010). *Linear algebra*. New Delhi: PHI Learning.
2. Cooperstein, B. N. (2015). *Advanced linear algebra*. (Advanced Linear Algebra, Second Edition.) Boca Raton: CRC Press.
3. Lang, S. (2011). *Linear algebra*. (3rd Ed.). New York: Springer.
4. Halmos, P. R. (2013). *Finite dimensional vector spaces*. (2nd Ed.). S.l.: Literary Licensing, LLC.
5. Yang, Y. (2015). *Advanced linear algebra.*Cambridge: Cambridge University Press.

Suggested E-learning Material:

1. Lecture Notes: https://nptel.ac.in/downloads/111102011/#
2. Video Lectures & Notes:https://onlinecourses.nptel.ac.in/noc17_ma04/preview

MATH 415Analysis-I

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**5**	**0**	**0**	**5**

Learning Outcomes:

On completion of the course, the student will be able to,

- understand modern theory of set and real numbers.
- investigate different metric spaces and their properties.
- master the technique of calculating the Lebesgue integral and understand the applications measurable functions.
- explain construction and investigate properties of Lebesgue measure.
- derive the Fourier series of integrable functions.
- discuss the point-wise and uniform convergence of series.

Section A

Countable & Uncountable sets, well ordering principle, Field of real numbers as a complete ordered field, Metric space, Sequences in metric spaces, complete metric space, Compact set, Heine-Borel Theorem, Bolzano Weierstrass Theorem.

Section B

Construction & Properties of Lebesgue measure, Borel sets, Measurable sets, Measurable functions, Lebesgue integration & its properties, Dominated & Monotone convergence theorems, Fatau's Lemma.

Section C

Fourier series of integrable functions. Discussion of pointwise & uniform convergence of series, Fejer's Theorem for continuous periodic functions, Orthogonality, Parseval's Theorem, Riez Fischer theorem.

Suggested Text Books:

1. Royden, H. L. (2011). *Real analysis*. (3rd Ed.). New Delhi: Prentice hall of India.
2. Barra, G. D. (2008). *Measure theory and integration*. New Delhi: New Age International.
3. Carslaw, H. S. (1959). *Introduction to the theory of Fourier's series and integrals*. New York: Dover Publications.

SuggestedReference Books:

1. Rudin, W. (2017). *Principles of mathematical analysis*. (3rd Ed.). Chennai: McGraw Education (india) Private Limited.
2. Apostol,T.M.(1974).*Mathematical analysis*.(2ndEd.).New Delhi:Narosa Publishing House.
3. Titchmarsh, E. C. (1968). *The theory of functions*. London: Oxford Univ. Press.
4. Hewitt, E., & Stromberg, K. R. (2009). *Real and abstract analysis: A modern treatment of the theory of functions of a real variable*. New York: Springer.
5. Goldberg, R. R. (2019). *Methods of real analysis*.New Delhi: Blaisdell Pub. Co.;Oxford and IBH.

Suggested E-learning material

1. A Basic Course in Real Analysis; NPTL:https://nptel.ac.in/courses/111105069/
2. Fourier Series Part-1;NPTL: https://nptel.ac.in/courses/122107037/24

MATH 420Discrete Mathematics

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

Learning Outcomes:

After completing the course, students will be able to

1. Understand logical arguments and logical constructs. Have a better understanding of sets, functions and relations.
2. Apply logical reasoning to solve a variety of mathematical problems.
3. Understand and apply the fundamental concepts in graph theory.
4. Acquire ability to apply graph theory-based tools in solving practical problems.
5. Improve the proof writing skills and able to develop mathematical maturity.

Section A

Logic, Propositional Equivalences, Predicates and Quantifiers, Nested Quantifiers, Methods of Proof, Multi-set, Relations and Functions, Introduction to Algorithms, The growth of functions, Complexity of Algorithms, Partially ordered sets, Chains and Anti-chains, Lattices, Complete lattices, Distributive lattices, Complements, Boolean Algebra, Uniqueness of Finite Boolean Algebras, Boolean expressions and Boolean functions, Normal forms.

Section B

Basic counting Principles, Permutations and Combinations, Permutations and Combinations on multi-sets, Generation of permutations and Combinations, Pigeon-hole principle, Principle of inclusion and exclusion. Discrete numeric functions, Generating Functions, Combinatorial problems. Recurrence relations, linear recurrence relation with constant coefficients and their solutions, Solution by the method of generating Functions.

Section C

Graphs, Vertices of graphs, degrees, Sub-graphs, Paths, Walks and cycles, Connected graphs, Connected components, Weighted graphs, Directed graphs. Matrix representations of graphs. Shortest path Problem Operations on graphs. Blocks, Cut-points, bridges Block graphs and Cut-point graphs. Euler tours, Euler graphs Hamiltonian paths, Hamiltonian graphs. Closure of a graph. Isomorphism in graphs. Euler's formula, Planar graphs, Vertex colouring Chromatic number, Chromatic polynomial, R - Critical graphs,

Acyclic graphs- Trees , Elementary properties of treesCenter, Connectivity, Connectivity and line connectivity, Partitions, Cut edges - Cut vertices, Spanning tree and minimum Spanning tree.

SuggestedText/Reference Books:

1. Liu, C. L. (1985). *Elements of discrete mathematics*. Mc-Graw Hill, International edition.
2. Deo, N. (2012). *Graph theory: With applications to engineering and computer science*. New Delhi: PHI Learning Private Limited.
3. Rosen, K. H. (2013). *Discrete mathematics and its applications: Seventh edition*. New York: McGraw-Hill.
4. Joshi, K. D. (1089). *Foundation of discrete mathematics*.Wiely Eastern Ltd.

Suggested E-learning Material:

1. Lecture notes: https://nptel.ac.in/downloads/111104026/
2. Lecture notes: http://home.iitk.ac.in/~arlal/book/mth202.pdf
3. Lecture notes:https://ocw.mit.edu/high-chool/mathematics/combinatorics-the-fine-art-of-counting/lecture-notes/MITHFH_lecturenotes_8.pdf
4. Lecture notes: http://www.math.kit.edu/iag6/lehre/graphtheo2015w/media/lecture_notes.pdf
5. Online Course:https://swayam.gov.in/courses/4926-discrete-mathematics
6. Online Course:https://swayam.gov.in/course/3795-graph-theory

STAT 402 Probability and Statistics

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

Learning Outcomes:

On completion of the course, the students will be able to:

- Understand the meaning of probability and probabilistic experiment
- Familiarize with the all approaches to probability theory and particularly, the axiomatic approach.
- Understanding the meaning of conditional probability, conditioning, and reduced sample space.

- Understand the concepts of random variables, sigma-fields generated by random variables, probability distributions and independence of random variables related to measurable functions.
- Distinguish between independent and uncorrelated random variables.
- Distinguish between discrete, continuous, and mixed random variables and be able to represent them using probability mass, probability density, and cumulative distribution function.
- Derive the distribution of functions of random variable.
- Understand the concepts of sampling distributions and use of sampling distribution in hypothesis testing.

Section A

Measures of Central Tendency: mathematical and positional. Measures of Dispersion, Review of probability, Random variable and functions of random variables: Probability density function, probability mass function, Distribution function and its properties. Mathematical expectation and its simple properties.

Section B

Moment generating function, characteristic function and their properties. Theoretical probability distributions with their simple properties, Discrete distribution: Bernoulli, Binomial, Poisson, Geometric distribution; Continuous distribution: Rectangular. Normal, Exponential and Cauchy distribution.

Section C

Sampling distribution of univariate normal, Chi square, t, F distribution with their simple properties and applications.

Bivariate data: simple, partial and multiple correlation (3 variables only), rank correlation and regression.

Suggested Text Books:

1. Goon, A. M., Gupta, M. K. and Gupta, B. D. (1968). *Fundamentals of Statistics*(Vol. I& Vol. II).World Press Pvt. Ltd., Kolkata.
2. Goon, A. M., Gupta, M. K. and Gupta, B. D. (1973). *An outline of Statistical Theory* (Vol. I& Vol. II). World Press Pvt. Ltd., Kolkata.

3. Srinivasan, S.K. & Mehta, K. M. (1978). *Probability and Random Process*. Tata Mc-Graw-Hill.

4. Kapoor, J. N. & Saxena, H.C. (2007). *Mathematical Statistics*. S. Chand & Company Ltd.

5. Rohtagi,V. K. (1976). *An Introduction to probability and Mathematical Statistics*. Wiley Eastern Publisher Ltd., New Delhi.

Suggested E-learning material:

1. Probability and Statistics; Platform: NPTEL nptel.ac.in/courses/111105041/.
2. Probability; Platform: e-PGPathshalahttps://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/.

Note: Use of Scientific Calculator of permissible.

CS 415 Computer Programming

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

Learning Outcomes:

On successful completion of the course students will be able to

- Understanding the concepts of computer basics and programming.
- Understanding of the organization and operations of a computer system.
- Understanding of Binary logic in design of electronic circuits.
- Students would have logical thinking for Analyzing problems, designing and implementing algorithmic solutions.
- Students would get the skills for the use of the C programming language to implement the real world applications.

Section-A

Fundamentals of Computer System: Block Diagram, CPU, Memory, Input/Output Devices. Hardware and Software, Booting Process and DOS Commands.

Steps in Program Development: Problem analysis, algorithms & flow charts, High level and low level programming languages.

Computer Programming Using C: History, Data types (simple and structured) and their representation, Constants and variables, Operators, Arithmetic's and logical expressions, Type casting, Input and output statements.

Section-B

Control Statements: Sequencing, Conditional and unconditional branching and looping.

Arrays: Single and multidimensional arrays, Arrays and strings, String built-in functions, Applications of arrays: Searching (linear and binary), Sorting (bubble, selection and insertion).

Structured Programming: Function declaration and definition, Function call, Passing parameters to the functions: call by value, call by reference. Returning values, Recursive functions, Passing arrays to functions.

Section-C

Storage classes in C: Automatic, Register, External, and Static.

Pointers: Pointer arithmetic, Pointers and arrays, Pointers and strings, Pointer to pointer, Dynamic Memory Allocation.

Derived Data Types: Structures, unions, Array of structure, Pointer to structure, enumerated data types.

File Handling in C: Types of files,Opening and closing a data file, reading and writing a data file, Random access in a file, Error handling during file I/O operations, Command line arguments.

Suggested Books:

1. Kanetkar, Y. P. (2009). *Let us C*. BPB Publications.
2. Sinha, P. K. (2004). *Computer Fundamentals: Concept, Systems and Applications*. BPB Publications.
3. Kernighan, B. W., & Ritchie, D. M. (2006). *The C Programming Language*. PHI Learning Pvt. Ltd., New Delhi.
4. Kanetkar, Y. P. (2009). *Understanding Pointers in C*. BPB Publications.
5. Dromey, R. G. (2007). *How to Solve it by Computer*. PHI Learning Pvt. Ltd . New Delhi.
6. Govil, Mahesh Chand, *Computer Fundamentals and Programming in C*, Jaipur Publishing House.
7. Venugopal, K. R. (2005). *Programming with C*. Tata McGraw-Hill.
8. Balagurusamy, E., (2010). *Programming in ANSI C*. Tata McGraw-Hill.

Suggested E-learning material:

1. Introduction to Programming in C: https://nptel.ac.in/courses/106104128/
2. Introduction to Programming in C: Specialization by Duke University

   https://www.coursera.org/specializations/c-programming
3. Computer Fundamentals by P. K. Sinha

   https://www.edutechlearners.com/computer-fundamentals-p-k-sinha-free-pdf/

CS 415LComputer Programming Lab

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Lab Number	**Problems**
L1-L3	Simple hands on computers and DOS Internal & External Commands
L4-L6	Simple Problems Using scanf and printf functions. Formula Based Problems using Constants, Variables and use of operators.
L7-L8	Use of Library Functions e.g. sqrt, sin, cos, log etc.
L9-L20	Loop Statement using for, while, do –while statement
L21-L25	Conditional Checking Using if statement, Nested if statement, switch statement and Unconditional goto
L26-L40	Problems based on array data types. Problems on One Dimensional Array-Searching (Linear, Binary), Sorting (Bubble, Selection, Insertion), Merging.
L41-L45	Problems on two Dimensional Array -Matrix Operation: Addition, Subtraction, Multiplication etc.
L46-L50	Problems based on pointers, Parameter passing in functions, Recursion
L51-L55	Declaration, Reading, Writing and manipulation on struct and union data type
L56-L62	File handling
L63-L64	Command line Arguments

MATH417LComputational Lab-I

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Learning Outcomes:

On completion of the course, the student will be able to,

- Perform basic mathematical operations in MATLAB.
- Create vectors, arrays, matrices and perform fundamental matrix operations.
- Visualize basic mathematical functions.
- Solve linear equations and system of linear equations.
- Import/export data, summarize and visualize the data.
- Fit some standard distributions and test hypothesis.

List of Practicals :

1. Introduction to MATLAB
2. Defining Vectors, Array, Matrices and their mathematical operations
3. Special variables and Numeric display formats
4. Matrix Functions: Norm, rank, determinant, transpose, inverse, g-inverse, diagonal, trace, etc.
5. Finding roots of a polynomial, characteristic equation, eigen values and eigen vectors
6. Solving system of linear equations: Gauss elimination Method, Matrix Decomposition: Cholesky, LU, and QR factorizations, diagonal forms, singular value decomposition.
7. 2D plots for Cartesian, parametric and polar curves
8. Evaluating and plotting: Trigonometric functions, hyperbolic functions, complex functions, Logarithms, exponentials, etc.
9. 3D plots: surfaces, contour plot, mesh
10. Data import and export
11. Building frequency tables: Univariate, Bivariate.
12. Finding descriptive statistics: averages, dispersion, skewness, kurtosis.
13. Data visualization: Dot plots, Histogram, Box plots, bar diagram, pie diagrams, etc.

14. Fitting and visualization of Probability distributions: Binomial, Poisson and Normal.
15. Empirical cumulative distribution function plot, Histogram based on empirical cumulative distribution function, Histogram with a distribution fit, Normal probability plot, Probability plots, Quantile-quantile plot.
16. Hypothesis Tests: t-test, F-test, chi-square goodness-of-fit test
17. Introduction to M-files and programming in MATLAB,

Suggested Books:

1. D. Duffy, Advanced Engineering mathematics with MATLAB, 3rd Ed, Taylor & Francis, 2010
2. A. Knight, Basics of Matlab and beyond, CRC Press, 1999

Suggested E-learning material:

1. PDF Documentation for MATLAB: https://in.mathworks.com/help/pdf_doc/matlab/index.html

MATH413Algebra-II

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**5**	**0**	**0**	**5**

Learning Outcomes:

After completing the course, students will be able

- To demonstrate the mathematical maturity of understanding the proof.
- To understand the algebraic structures groups, rings, modules.
- To grasp the significance of the concepts of homomorphism &isomorphism and be able to check a given function is one of these.
- To understand the class equation for a finite group and its applications in Sylows theorems.
- To classify groups up to isomorphism.
- To really understand the special types of rings and be able to construct new examples from the old ones.
- To check a subset of a ring is an ideal or not and be able to identify proper and maximal ideal.

- To understand the concept of unique factorization domain and able to write a polynomial as the product of irreducible factors
- To describe as a generalization of vector space and able to understand types of modules.
- To grasp the concept of Artinian modules, Northerian modules, Artinian rings and Northerian rings.

Section A

Review of groups, direct product of groups, normal subgroups, quotient groups, isomorphism theorems,Conjugates, Conjugacy in S_n, Class equation for a Group, Sylow's Theorems, Applications of Sylow's theorem, Simplicity of Alternating Group A_n for $n>5$.

Section B

Rings, Ring homomorphism and quotient rings, Ideals: Prime and Maximal, fields of fractions, Divisibility, Euclidean and Principal Ideal Domains, Unique Factorization Domains, Polynomial Rings over fields, irreducibility criteria.

Section C

Modules, Quotient modules, module homomorphisms, generation of modules, direct sums, free modules, modules over PID's, Chain conditions, Artinian modules, Northerian modules, Composition series, Modules of finite length, Jordan Holder Theorem, Artinian rings, Northerian rings, Hilbert Basis Theorem, I.S.Cohen's Theorem, Introduction of Nil radical and Jacobson radical.

Suggested Books:

1. Gallian, J. A. (2013). *Contemporary abstract algebra*. (8th Ed.). Boston, MA: Brooks/Cole Cengage Learning.
2. Dummit, D. S. & Foote, R. M. (2004). *Abstract algebra*(3rd Ed.).New Jersey:Wiley.
3. Musili, C. (1994)*Introduction to Rings and Modules* (2nd Ed.).New Delhi:Narosa Publishing House.
4. Hungerford, T. W. (2014) *Abstract algebra: An introduction*(3rd Ed.).Australia: Brooks/Cole Cengage Learning.
5. Hillman A. P. &Alexandersor, G. L. (2015)*Abstract algebra: A first undergraduate course*(5th Ed.). CBS Publishers & Distributors Pvt. Ltd.
6. Fraleigh, J. B. (2003). *A first course in abstract algebra* (7th Ed.).Harlow: Pearson.

7. Sen, M. K., Ghosh, S., Mukhopadhyay, P. &Maity, S. K. (2019)*Topics in abstract algebra*(3rd Ed.).University Press.
8. Herstein, I. N. (1991)*Topics in algebra* (2nd Ed.).New Delhi: Wiley Eastern.

Suggested E-learning Material:

1. Lecture Notes on Groups and Rings: https://ocw.mit.edu/courses/mathematics/18-703-modern-algebra-spring-2013/related-resources/
2. Video Lectures on Algebra: https://www.extension.harvard.edu/open-learning-initiative/abstract-algebra
3. Open Source Book Abstract algebra: Theory and applications by Thomas W. Judson http://abstract.ups.edu/download/aata-20110810.pdf

MATH416Analysis-II

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**5**	**0**	**0**	**5**

Learning Outcomes:

On completion of the course, the student will be able to,

- demonstrate understanding of the basic and advanced concepts underlying complex analysis.
- demonstrate familiarity with a range of examples of these concepts.
- prove advanced results/theorems in complex analysis.
- apply the methods of complex function theory to evaluate integrals and infinite series of complex functions.
- demonstrate understanding and appreciation of a more deeper aspects of complex function theory.
- demonstrate skills in communicating mathematics orally and in writing.

Section A

The complex number systems, stereographic projection, Riemann sphere, review of basic analysis. Analytic (Holomorphic) functions, Cauchy-Riemann equations, harmonic functions, line integrals and Green's theorem. Independence of path, harmonic conjugates in star-shaped domain, complex line integrals. Fundamental theorem of calculus for analytic functions, Cauchy's theorem, Cauchy's integral formula and its generalized form,

Cauchy's estimates, Liouville's theorem, Morera's theorem. Maximum and minimum modulus principle.

Section B

Power series, Abel' convergence lemma, Cauchy-Hadamard formula, power series expansion of an analytic function, zeros of an analytic function. Winding number, Laurent's expansions, isolated singularities, entire and meromophic functions, Casorati and Weierstrass theorem. Residue at a singularity, residue theorem.

Section C

Argument principle, Rouche's theorem, residue and contour integration, Hurwitz theorem. Open mapping theorem. Inverse function theorem. Fundamental theorem of algebra. Gauss theorem, conformal mapping and fractional linear transformation, Tranformationsw = z^2, w = e^z, w = e^{-z} , w = log z, w = sin z, w =cos z. Schwarz lemma, conformal self maps of the unit disk. Pick's lemma, Poisson integral formula, Analytic continuation.

Suggested Books:

1. Gamelin, T. W. (2004). *Complex analysis*. New Delhi: Springer.
2. Conway, J. B. (1995). *Functions of one complex variable*. New York: Springer-Verlag.
3. Ponnusamy, S. (2007). *Foundations of complex analysis*. (2nd Ed.). Oxford, UK: Alpha Science Internat.
4. Ahlfors, L. V. (2013). *Complex analysis: An introduction to the theory of analytic functions of one complex variable*. (3rd Ed.). India: McGraw Hill Education.

Suggested E-learning material

1. Complex Analysis; NPTL:https://nptel.ac.in/courses/111103070/

MATH422Ordinary Differential Equations

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

Learning Outcomes:

On completion of the course, students will be able to

- Understand the existence and uniqueness of IVPs and their solution

- Understand method of successive approximations, variation of constants, annihilator method, and reduction of order of a homogeneous equation.
- Solve linear differential equations of higher order with variable coefficients.
- Solve boundary value problems for second order equations.
- Solve Boundary Value problems for second order equations by Green's function, Strum-Liouville Boundary Value problem.
- Grasp the concept of the stability of system of differential equations
- Solve system of linear differential equations and study the qualitative behavior of these systems.

Sections A

Existence and Uniqueness of solutions: Introduction, Picard's Successive Approximations, Picard's theorem, Continuation and dependence of initial conditions, Existence of solutions in the large, Existence and Uniqueness for systems, fixed point technique for nonlinear differential equations.

Section B

Linear Differential equations of higher order with variable coefficients: Introduction, Existence and Uniqueness theorem, linear dependence and Wronskian. Solution Method of variation of parameters, Method of undetermined coefficients, Reduction of order.

Boundary Value Problems for second order equations: Introduction, Green's function, Sturm Liouville problem. Applications of BVPs.

Section C

System of linear differential equations: Introduction, Existence and Uniqueness theorem, Solution of the system; Eigenvalue–Eigenvector Method and Fundamental Matrix Method. Matrix Exponential Function, Non-homogeneous linear systems. Phase Portrait in R^2. Plane Autonomous Systems: critical points and types of critical points and stability.

Text Books:

1. Deo, S. G., Raghavendra, V., Kar, R. &Lakshmikantham, V. (2015) *Textbook of ordinary differential equations.* (3rd Ed.).New Delhi: Mc Graw Hill Education.
2. Ahmad, S. &Ambrosetti, A. (2015). *A Textbook on Ordinary Differential Equations.* (2nd Ed.). Switzerland: Springer.

Reference Books:

1. Wirkus, S.A. & Swift, R.J. (2015). *Ordinary Differential Equations*. (2nd Ed.). USA: CRC Press.
2. Birkhoff, G. & Rot, G.C. (1989). *Ordinary Differential Equation.* (4th ed.), India: John Willey.
3. Braun, M. (1975). *Differential Equations & their Applications.* New York: Springer Verlag.
4. Coddington, E.A. & Levinson, N. (1955). *Theory of ordinary differential equation.* New York: Mcgraw Hill.
5. Ross, S. L. (1984). *Differential Equations.* (3rd ed.). India: Wiley Publication.
6. William E. B., & Richard C. D. (2012). *Elementary Differential Equations and Boundary Value*. (10^{th}Ed.). New York: Wiley Publication.
7. Coddington, E. A. (1961). *An Introduction to Ordinary differential equations*. New Jersey, USA: Dover Publication Inc.
8. Hartman, P. (1964). *Ordinary Differential Equations*. New York; John Wiley and sons.

Suggested E-learning material

1. Lecture notes: http://www.math.ust.hk/~machas/differential-equations.pdf
2. NPTEL: https://nptel.ac.in/courses/111106100/
3. Lecture Notes:http://home.iitk.ac.in/~sghorai/TEACHING/MTH203/ode.html

MATH423Topology

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

Learning Outcomes:

Upon successful completion of this course, student will be able to

- Define andillustrate the concept of topological spaces and continuous functions.
- Defineand illustrate the concept of product topology and quotient topology.
- Calculate simple topological invariants, such as the number of path components.

- Define and illustrate the concepts separation axioms.
- Use continuous functions and homeomorphisms to understand structure of topological spaces.

Section A

Infinite sets and axiom of choice, Well-ordered sets, The maximum principle, Topological spaces, Bases for a topology, The order topology, The product topology, The subspace topology, Closed sets and limit points, Continuity of a function, Homeomorphism, Construction of continuous functions.

Section B

Metric topology, The quotient topology (Introduction only), Connected spaces, Path connected spaces, Connected sets in the real line, Components, Path components, Local connectedness, Local path connectedness, Compact spaces.

Section C

First countability axiom, Second countability axiom, Lindelof space, Regular space, Normal spaces, The Urysohn Lemma, Completely regular space. The Tietze extension theorem.

Suggested Books:

1. Munkres, J. R. (1975). *Topology: A first course***.**New Delhi: Prentice Hall of India.
2. Singh, T. B. (2013). *Elements of topology*. CRC Press.
3. Joshi, K. D. (1986). *Introduction to general topology*. NewDelhi: Wiley Eastern.
4. Murdeshwar, M. G. (1983). *General topology*.New Delhi: Wiley Eastern.
5. Simmons, G. F. (1963). *Introduction to topology & modern analysis.*Auckland:McGraw Hill.
6. Dugundji, J. (1990). *Topology,*New Delhi: Universal Book Stall.

Suggested E-learning Material:

1. Video Lectures: https://nptel.ac.in/courses/111106054/

MATH409Numerical Analysis

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Demonstrate numerical methods to obtain approximate solutions to mathematical problems.
- Derive numerical methods for various mathematical operations and tasks, such as interpolation, differentiation, integration, the solution of linear and nonlinear equations, and the solution of ordinary differential equations.
- Analyze the appropriate numerical method to find the Eigen values and corresponding eigenvectors of a system.
- Use rational approximation of a function like Padé approximant for power series.
- Solve the boundary value problems using shooting method and finite difference method.
- Define and use the concepts accuracy, consistence, stability and convergence.

Section A

Accuracy and approximate calculations: Different types of errors and their computations.

Numerical solution of system of linear equations: Direct methods: Gauss elimination method and Crout's (factorization) methods, Iterative methods: Jacobi method, Gauss-Seidel method, Vector and matrix norm, Condition number and ill-conditioning, condition of convergence in iterative methods.

Eigen values and Eigen vectors: Singular value decomposition, Power method, Aitken's acceleration, Inverse Power method.

Section B

Numerical solutions of algebraic and transcendental equations: Polynomial and transcendental equations, intermediate value theorem, Bisection method, Iterative method, Newton-Raphson method, Convergence analysis of these methods.

Interpolation: Newton-Gregory forward and backward interpolation, Lagrange's formula, inverse interpolation, computation errors in these formulae and analysis of errors, **Approximation of function:** Padé approximation.

Numerical Differentiation: Maximum and minimum value of a tabulated function, Solution of difference equations, **Numerical Integration:** Newton-cotes integration formula, Trapezoidal, Simpson's 1/3 and Simpson's 3/8 and Weddle's rules, Gaussian quadrature formula.

Section C

Numerical solution of ordinary differential equations: Initial value problems: Lipschitzcondition for initial value problems, solution by Taylor's series method, Euler's method, Picard's method, Runge-Kutta methods, Runge-Kutta-Fehlberg method, Predictor corrector methods: Milne's method, estimation of errors, **Boundary value problems**: Shooting Method, Finite difference method, Rayleigh-Ritz method. Stability analysis of these numerical methods.

Suggested Text Books:

1. Cheney, E. W., & Kincaid, D. (2008). *Numerical mathematics and computing* (5th ed.). Thomson Brooks/Cole.
2. Jain, M. K., Iyengar, S. R. K., & Jain, R. K. (2007). *Numerical methods for scientific and engineering computation* (5th ed.).New Delhi: New Age International.
3. Sastry, S. S. (2012). *Introductory methods of numerical analysis* (5th ed.). New Delhi: Prentice-Hall of India.

Suggested Reference Books:

1. Burden, R. L., &Faires, J. D. (2005). *Numerical analysis* (7th ed.). Thomson Brooks/Cole.
2. Chauhan, D. S., Vyas, P., &Soni, V. (2014). *Studies in numerical analysis* (Reprint ed.), Jaipur Publishing House.
3. Rao, K. S. (2005), *Numerical methods for scientists and engineers* (2nd ed.). New Delhi: Prentice-Hall of India.
4. Phillips, G. M., & Taylor, P. J. (1996). *Theory and applications of numerical analysis* (2nd ed.). Elsevier.

Suggested E-learning material:

1. Introduction to Numerical Analysis for Engineering, Platform: MIT open courseware

   https://ocw.mit.edu/courses/mechanical-engineering/2-993j-introduction-to-numerical-analysis-for-engineering-13-002j-spring-2005/index.htm
2. Numerical Analysis, Platform: nptel

   https://nptel.ac.in/courses/111107062/
3. Elementary Numerical Analysis, Platform: nptel

   https://nptel.ac.in/courses/111101003/

MATH409LNumerical Analysis Lab

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Learning Outcomes:

On completion of the course, the student will be able to,

- Implement numerical methods in MATLAB to solve systems of linear equations, compute quadrature, solve ordinary differential equations and various computational problems.
- Write efficient, well-documented MATLAB code and present numerical results in an informative way.
- Show logical thinking in coding a mathematical problem in algorithmic form.
- Use their knowledge of a programming in MATLAB to learn more easily any other programming language like Mathematica, Python etc.

1. A review of basic MATLAB functions on command window.
2. Writing Scripts and functions in MATLAB (m-files).
3. Flow control commands (If-else, for, while, switch).
4. An M-file to implement Gauss elimination method with partial pivoting for solving system of linear equations.
5. An M-file to implement Gauss-Seidel method.
6. An M-file to implement the bisection method.

7. An M-file to implement Newton-Raphson method for nonlinear equations.
8. An M-file to implement Newton's interpolation.
9. An M-file to implement Lagrange's interpolation.
10. Curve fitting: least-squares n^{th} order polynomial to data (liner and Quadratic).
11. An M-file to implement the trapezoidal and Simpson's rules.
12. An M-file to implement Euler's method for solving ordinary differential equations with a plot of exact and numerical solutions.
13. An M-file to implement Runge-Kutta methods (ode23 and ode45) for solving ordinary differential equations with a plot of exact and numerical solutions.
14. An M-file to implement finite difference method for solving ordinary differential equations with a plot of exact and numerical solutions.

Text Books/ Reference Books:

1. Fausett, L. V. (2008). *Applied numerical analysis using MATLAB* (2^{nd} ed.). Pearson Education.
2. Chapra,S. (2006). *Applied numerical methods with MATLAB for engineers and scientists*, McGraw-Hill Higher Education.

Suggested E-learning material:

1. Introduction to Numerical Methods and MATLAB Programming for Engineers, Platform: Ohio University;
   http://www.ohiouniversityfaculty.com/youngt/IntNumMeth/
2. Using numeric approximations to solve continuous problems, Platform: MathWorks;
   https://in.mathworks.com/discovery/numerical-analysis.html

MATH418LComputational Lab-II

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Learning Outcomes:

On successful completion of the course, the students will be able to,

- Understand the fundaments of procedural and functional programming with Mathematica software;

- Efficiently use these technical computing systems in one's studies and research.
- Set up simple engineering problems such that they can be solved and visualized using basic codes.

1. Introduction to Wolfram Mathematica: Entering input, variables, assignment, execution, and evaluation of mathematical functions, rules and replacement, Notebooks in Mathematica.
2. Basic commands of Mathematica, Trigonometry.
3. Calculus: Roots of polynomials, partial fractions, differentiation, limits and expansions, integration, Optimization.
4. Lists and Matrices: Matrix Operations, transpose, determinant, inverse of a matrix, Index Notation.
5. Linear Algebra: Characteristic equation, Eigen values and Eigenvectors, Row reduced echelon form and normal form, Vector Spaces, Linear Transformations, Solutions to system of linear equations.
6. Graphics: Plotting of simple functions, Two- and Three-dimensional Plotting (Cartesian, parametric and polar equations, Vector plots), Graphics Primitives, and Formatting.
7. Differential equations: analytic and numerical solutions of ODEs, Plotting of second order solution family of differential equation, System of ODEs (critical points, phase portrait diagrams and time series plots).
8. Plotting of recursive sequences.
9. Study the convergence of sequences through plotting.
10. Verify Bolzano-Weierstrass theorem through plotting of sequences and hence identify convergent subsequences from the plot.
11. Study the convergence/divergence of infinite series by plotting their sequences of partial sum. Cauchy's root test by plotting nth roots.
12. Ratio test by plotting the ratio of n^{th} and $(n+1)^{th}$ term.

Suggested Readings:

1. The Mathematica Book, Fifth Edition by Stephen Wolfram; https://www.wolfram.com/language/elementary-introduction/2nd-ed/
2. Lecture Notes on Mathematics for Materials Scientists and Engineers;

   https://ocw.mit.edu/courses/materials-science-and-engineering/3-016-mathematics-for-materials-scientists-and-engineers-fall-2005/lecture-notes/

STAT407Statistical Inference

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**5**	**0**	**0**	**5**

Learning Outcomes:

After successful completion of this course, student will be able to:

- Apply various parametric, non-parametric and sequential estimation techniques andtesting procedures to deal with real life problems.
- Understand confidence interval, Neyman-Pearson fundamental lemma, UMP test, Interval estimation.
- Understand SPRT, OC and ASN function.
- Understand non-parametric methods, U-statistic.

Section A

Properties of a good estimator: Unbiasedness, consistency, efficiency and sufficiency. Minimal sufficient statistics Complete sufficient statistics, Rao-Blackwell theorem, LehmannScheffe theorem, Cramer Rao lower bound for minimum variance unbiased estimator (MVUE).

Section B

Methods of estimation: Maximum likelihood estimator (MLE) and its small sample properties, Moment estimator.

Interval estimation, Confidence interval for normal case, relation with testing of hypothesis, MP tests, NeymanPearson lemma, UMP tests.

Section C

Sequential test procedure, Sequential probability ratio test (SPRT), Operating characteristic (OC) and Average sample number (ASN) function.

Non-parametric tests: Tests of goodness of fit, Run test, Kolmogorov-Smirnov test, Sign test, Wilcoxon signed rank test, Mann-Whitney U test.

Text Books:

1. Zacks, S. (1971). *The theory of statistical inference.* John Wiley & Sons.
2. Rajagopalan, M. &Dhanavanthan, P.(2012). *Statistical Inference.* PHI learning privet Ltd.

Reference Books:

1. Casella, G. & Berger, R.L. (2002). Statistical inference (2nd. ed.). Duxbury Advanced Series.

2. Rohatgi, V. K., & Saleh, A. M. E. (2015). An introduction to probability and statistics. (2nd.ed.) John Wiley & Sons.
3. Kale, B. K. &Muralidharan, K. (2015). A first course on parametric inference. Alpha Science International Ltd.
4. Rao, C.R. (2010).Linear Statistical Inference and Its Applications (2nd. ed.). Wiley Eastern Ltd.
5. Goon, A.M. & Gupta, M.K. and Gupta, B.D.(2016). An Outline of Statistical Theory (Vol. II).The world Press Pvt.Ltd.
6. Lehmann, E. L., & Casella, G. (2006). Theory of point estimation. Springer Science & Business Media.
7. Lehmann, E. L., & Romano, J. P. (2006). Testing statistical hypotheses. Springer Science &Business Media.
8. Shao, J.(2010). Mathematical Statistics (2nd. ed.). Springer.

Suggested E-Learning Material:

1. Statistical Inference; Platform: MITOPENCOURSEWARE https://ocw.mit.edu/index.htm
2. Statistical Inference; Platform: Coursera https://www.coursera.org
3. Statistical Inference:Platform: e-PG Pathshalahttps://epgp.inflibnet.ac.in

STAT406Measure Theory and Advanced Probability

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

Learning Outcomes:

On successful completion of this unit, students will be able to:

- Understand the basic concepts of measure and integration theory.
- Understand of the theory on the basis of examples of application.
- Use abstract methods to solve problems and to use a wide range of references and critical thinking.
- Use weak and strong law of large numbers in statistical theory.

Section A

Measure Theory-Fields, Sigma Fields, Monotone Classes, Set Functions, Measure, Outer Measure, Carotheodory's Extension Theorem. Probability Measure, Lebesgue Stieljes Measure. Measurable Functions, Monotone and Dominated Convergence Theorem. Product Spaces, Fubini's Theorem (without proof).

Section B

Sequences of Distribution Function, convergence: convergence in distribution, convergence in probability, almost sure convergence, convergence in Mean Square. Helly Bray theorem, Borel-Cantelli lemma and zero one law. Characteristics function, inversion and continuity theorem.

Section C

Inequalities: Cauchy-Schwartz inequality, Chebychev's inequality, Holder Inequality, Minkowski Inequality, Jensen Inequality. Weak and strong Law of Large Numbers-Khintchine, Kolmogorov theorem. One Dimensional Central Limit theorem- Lindeberg Levy, Lyapunov, Lindeberg Feller theorem.

Suggested Text/ Reference Books:

1. Feller, W. (2008). *An Introduction to probability theory and applications* (Vol.I& Vol.I). John Wiley & Sons.
2. Chung, K. L. (2011). *A Course in Probability Theory* (3rd ed.). San Diego, Academic Press.
3. Bhatt, B.R. (2019). *Modern Probability Theory* (4th ed.). London, UK : New Academic Science.
4. Rohatgi, V.K. (2000). *An Introduction to probability theory and mathematical statistics* (2nd ed.). Wiley series in probability and statistics.
5. Halmos, P.R. (2013). *Measure Theory* (Vol. 18). New York: Springer.
6. Bauer, H. (1981). *Probability theory and element of measure theory* (2nd ed.).London: Academic Press.

Suggested E-Learnings Material:

1. Measure Theory: www.math.tifr.res.in/~publ/ln/tifr12.pdf
2. Measure Theory and probability: https://www.math.ucdavis.edu/~hunter/measure_theory/
3. CLT and applications: https://newonlinecourses.science.psu.edu/stat414/node/133/

CS 417Database Management Systems

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

Learning Outcomes:

On successful completion of the course students will be able to

- Describe data models and schemas in DBMS
- Understand the features of database management system and Relational databases.
- Use SQL -the standard language of relational databases.
- Understand the functional dependencies and design of the database.
- Understand the concept of Transaction and Query processing.

Section-A

Introduction : Database system concepts and architecture, Data models schema and instances, Data independence and database language and interface, Data definition languages, DML, Overall database structure.

Data modeling using Entity Relationship Model : E. R. model concepts, notation for ER diagrams, mapping constraints, Keys, Concept of super key, candidate key, primary key, Generalization, Aggregation, reducing ER diagrams to tables, extended ER model, Relationship of higher degree.

Relational Data Model and Language : Relational data model concepts, relational algebra, relational calculus, tuple and domain calculus, SQL, data definition queries and updates in SQL, integrity constraints, Keys-constraints, domain constraints, referential integrity, assertions, security of databases.

Section-B

Example DBMS System (Oracle 8) : Basic architecture, data definition and data manipulation, ISQL, PLSQL, cursors, triggers, stored procedures.

Database design : Functional dependencies, normal forms, first, second and third functional personal normal forms. BCNF, multivalued dependencies, fourth normal forms, join dependencies and fifth normal forms. Steps in database design.

Query processing: Steps of Query Processing, Measures of Query Cost, Selection Operation, Sorting, Join Operation, Evaluation of Expressions.

Section-C

Query Optimization: Catalog Information for Cost Estimation, Estimation of Statistics, Transformation of Relational Expressions, Dynamic Programming for Choosing Evaluation Plans.

Transaction processing concepts. Concurrency control techniques, locking techniques, and time stamping and concurrency control.

Recovery-Log-Based, Shadow Paging, Recovery with concurrent Transactions Distributed databse systems: Fragments of Relations, Optimization transmission cost by semi joins, Distributed concurrency control, Management of deadlocks.

Suggested Books:

1. Korth Henry F., Silberschatz Abraham, & Sudarshan S. (2006). *Database System Concepts* (5th ed.). Tata McGraw-Hill.
2. Murdick, R. G., Ross, J. E., & Claggett, J. R. *Information Systems for Modern Management*. Prentice Hall Professional Technical Reference.
3. Date C.J. *An Introduction to Database Systems.* Addison Wesley.
4. Majumdar & Bhattachrya. *Database Management System*. Tata McGraw-Hill.
5. Ramakrishnan, R., & Gehrke, J. (2000). *Database Management Systems*. Tata McGraw-Hill.
6. Leon, A., & Leon, M. (2010). *Database Management Systems*. Vikas Publishing House Pvt. Limited.

Suggested E-material:

1. Data Base Management System

   https://nptel.ac.in/courses/106105175/
2. Database Management Essentials by University of Colorado

   https://www.coursera.org/learn/database-management
3. Database System Concepts by Abraham Silberschatz, Henry F. Korth and S. Sudarshan

   https://kakeboksen.td.org.uit.no/Database%20System%20Concepts%206th%20edition.pdf

CS 417LDatabase Management Systems Lab

Max. Marks : 100	L	T	P	C
(CA: 40 + ESA: 60)	0	0	4	2

Lab	Problem
1-5	Basic DDL commands(Create,Drop,Alter) with integrity constraints
6-10	DML & DCL commands (Insert, Update, Delete, Select, Commit, Rollback)
11-13	Operators (Arithmatic,Logical,Relational etc.)
14-18	Assignment based on DDL and DML with conditions also Joins (Self join, inner join, outer join, equi join)
19-20	Complex queries (Retrieval of data from more than one table)
21-25	PL/SQL Block,Loops
26-27	Cursors, Triggers, Procedure, Function
28	Assignment of PL/SQL
29-32	Forms and report using front and tool. Connecting of database

MATH 531Advanced Calculus

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Analyzevector functions to find derivatives, tangent lines, integrals, and arc length.
- Evaluateintegrals of functions or vector-related quantities over curves, surfaces, and domains in two- and three-dimensional space.
- Use the Lagrange multiplier method to find extrema of functions with constraints.
- Solve problems involving tangent planes and normal lines.

Section A

Euclidean Space R^n, Basic Topology on R^n, Functions on Euclidean spaces, continuity, Uniform Continuity, differentiability; partial and directional derivatives.

Affine functions, First order approximation of Real valued functions, quadratic functions, Hessian Matrices, second order approximation and second derivative test.

Section B

Linear mappings and Matrices, The derivative matrix, First order approximation Theorem for mappings, Chain Rule, Inverse Function Theorem, Implicit Function Theorem, Lagrange Multipliers.

Section C

Riemann Integral of real-valued functions on Generalized rectangles, Continuity and integrability, Integration of functions on Jordan Domains, Fubini's Theorem, Change of Variables.

Suggested Text Book:

1. Fitzpatrick, P. (2009). *Advanced calculus*. Providence, R.I: American Mathematical Society.

Suggested Reference Books:

1. Munkres, J. R. (2018). *Analysis on manifolds*. Boca Raton, FL: CRC Press/Taylor & Francis Group/Advanced Book Program.
2. Folland, G. B. (2009). *A guide to advanced real analysis*. Washington, D.C.: Mathematical Association of America.
3. Rudin, W. (2017). *Principles of mathematical analysis*. Chennai: McGraw Education (India) Private Limited.

Suggested E-learning material

1. Lecture Notes on Multivariable Calculus; Platform: NPTEL https://nptel.ac.in/courses/111107108/

MATH 542Functional Analysis

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

Learning Outcomes:

On completion of the course, the student will be able to,

- explain the basic concepts of Functional Analysis, including the study of operator theory and the study of topological function spaces.
- describe how to illustrate the abstract notions in functional analysis via examples.
- apply Hilbert space-theory, including Riesz' representation theorem and weak convergence, and methods in problem solving.
- solve the problems appear in PDEs via the powerful tools from functional analysis,
- study in a range of other fields, e.g. Quantum Theory, Stochastic calculus and Harmonic analysis.

Section A

Normed spaces, Banach spaces, Further properties of Normed spaces, subspaces, Linear operators, linear functionals, Bounded and continuous linear operators, Normed spaces of operators, Dual spaces.

Section B

Hahn-Banach theorem (Extension of linear functionals) for normed spaces, application to bounded linear functionals on C[a,b], adjoint operators, reflexive spaces, uniform boundedness theorem, convergence of sequence of operators and functionals, Open mapping theorem, closed linear operators, Closed Graph Theorem.

Section C

Inner product spaces, Hilbert spaces, further properties of inner product spaces, orthogonal complements and direct sums, orthonormal sets and sequences, total orthonormal sets and sequences, representation of functionals on Hilbert spaces, Hilbert adjoint operators, Self-adjoint, unitary and normal operators.

Suggested Text Books:

1. Kreyszig, E. (2008). *Introductory functional analysis with applications*. New York: Wiley.

2. Jain, P. & Ahuja, O. P. (2011). *Functional analysis*. New Delhi: New Age International.

Suggested References Books:

1. Bachman, G., &Narici, L. (2012). *Functional Analysis*. New York: Dover Publications.
2. Simmons, G. F. (2004). *Introduction to topology and modern analysis*. New Delhi: TATA McGraw-Hill.
3. Rudin, W. (2006). *Functional analysis*. New York: McGraw-Hill.

Suggested E-learning material

1. Introduction to Functional Analysis; Platform: MITOPENCOURSEWARE https://ocw.mit.edu/courses/mathematics/18-102-introduction-to-functional-analysis-spring-2009/
2. Functional Analysis; Platform; NPTELhttps://nptel.ac.in/courses/111105037/
3. Functional Analysis; Platform: Free video lectureshttps://freevideolectures.com/course/3145/functional-analysis

MATH 550Operations Research

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Build a mathematical programming model of a real-life situation
- Write a report that describes the formulation of a linear programming problem, and able to presents and interprets the solutions.
- Understand the basic theory in linear programming.
- Apply a suitable method in research to develop the theories which will be applicable in the real-life problems.
- Understand the concepts of dynamic programming, job sequencing, network analysis.
- Understand the basic concepts and need of inventory theory and queueing theory.

Section A

Linear Programming: Simplex method, Theory of simplex method, Duality in linear programming. Dual simplex method. Assignment and Transportation Problem.

Section B

Dynamic Programming: Introduction, characteristics of dynamic programming, dynamic programming algorithm, solution of discrete dynamic programing problem.

Sequencing Problem: Introduction, processing *n* jobs through two machines, processing *n* jobs through *k* machines, processing two jobs through k machines.

Network Analysis, Introduction of Network analysis, shortest path problem PERT & CPM Updating of PERT charts.

Section C

Queueing Theory, Probability description of arrivals and service times, objectives and different characteristics of a queuing system, deterministic queuing system, steady-state behaviour of Markovian and Earlangian Models (M/M/1, M/M/C, M/Ek/l).

Inventory Theory, Deterministic economic lot size models and their extensions, models with lost sales and partially backlogged, continuous production with varying demand rates.

Suggested Books:

1. Swarup, K., Gupta, P. K., & Mohan, M. (1977). *Operations Research (Answers to problems)*. New Delhi: Sultan Chand & Sons.
2. Pant, J. C. (2004). *Introduction to optimization: Operations Research*. New Delhi: Jain Brothers.
3. Taha, H. A., & Pearson Education. (2017). *Operations research: An introduction*. Harlow [i 21 pozostałych: Pearson.
4. Hillier, F. S., & Lieberman, G. J. (1972). *Introduction to operation research*. San Francisco: Holden-Day.
5. Sinha, S. M. (2006). *Mathematical programming: Theory and methods*. New Delhi: Elsevier.

Suggested E-learning material:

1. Tutorial: https://ibmdecisionoptimization.github.io/tutorials/html/Linear_Programming.html

2. Tutorial: Sophia Learning: https://www.sophia.org/tutorials/linear-programming--5
3. Lectures – NPTEL: https://nptel.ac.in/courses/111102012/
4. Nonlinear Programming – MIT http://web.mit.edu/6.252/www/.
5. Nonlinear Programming: https://ocw.mit.edu/courses/sloan-school-of-management/15-084j-nonlinear-programming-spring-2004/lecture-notes/

STAT 532Survey Sampling

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

Learning Outcomes

- Understand the distinctive features of sampling schemes and its related estimation problems.
- Learn about various approaches (design based and model-based) to estimate admissible parameters; with and without replacement sampling scheme, sampling with varying probability of selection.
- Learn about the methods of post–stratification (stratified sampling) and controlled sampling and also double sampling procedure with unequal probability of selection.
- Learn about the applications of sampling methods; systematic, stratified and cluster sampling.
- Understand the cluster and two stages sampling with varying sizes of clusters/first stage units.
- Understand the super population approach to estimation.
- Understand non sampling error and estimation techniques in presence of non response.

Section A

Review of Simple random Sampling, Stratified Sampling, Cluster sampling with equal/unequal sample sizes, double sampling, Post and deep stratification, Sampling with varying probability of selection with replacement and without replacement, Midzuno Sen and Narain methods of sampling.

Section B

Horwitz-Thompson estimates, Desraj ordered estimator, Lahiri's method and cumulative total, Yates and Grandy estimate of variance its non-negativity.

Auxiliary variable: Ratio, product and regression method of estimation, Quenouille's techniques of bias reduction,Hortley and Ross unbiased ratio type estimator. Ratio and Regression estimators with combined and separate type estimates, two phase sampling (double sampling) in Ratio and Regression estimation.

Section C

Non-sampling errors: Incomplete samples effect of non response, Hensen and Hurvitz technique, Politz – Simmon's "not at home" method, Interpenetrating samples.Randomized response techniques – both qualitative and quantitative.

Suggested Readings

1. Cochran, W. G. (2007). *Sampling techniques(3rd. ed.)*. John Wiley & Sons.
2. Raj, D., & Chandhok, P. (1998). *Sample survey theory*. Narosa.
3. Chaudhuri, A. (2014). *Modern survey sampling*. CRC Press.
4. Chaudhuri, A. (2016). *Randomized response and indirect questioning techniques in surveys*. Chapman and Hall/CRC.
5. Sukhatme, P. V. (1963). *Sampling theory of surveys with applications*. The Indian Society Of Agricultural Statistics; New Delhi.
6. Murthy, M.N. (1967). *Sampling Theory and Methods. (2nd ed.)*. Statistical Publishing Society, Calcutta.
7. Singh, D. & Chaudhary, F.S. (2018). *Theory and Analysis of Sample Survey Design*. New Age International (P) Ltd.
8. Goon, A. M., Gupta, M. K., & Dasgupta, B. (2016). *Fundamental of Statistics Vol. II*. World Press.
9. Chaudhuri, A. (2016). *Randomized response and indirect questioning techniques in surveys*. Chapman and Hall/CRC.
10. Chaudhuri, A. (2013): *Essentials of Survey Sampling*, PHI Learning Pvt. Ltd, Delhi.

Suggested E-learning material

1. Design of experiment and sample surveys; Platform: e-PG Pathshala https://epgp.inflibnet.ac.in
2. Survey Sampling; Platform: University Library - The University of Adelaide

   https://www.adelaide.edu.au/library/
3. Survey Sampling; Platform: MITOPENCOURSEWARE https://ocw.mit.edu/index.htm

STAT 529Time Series and Stochastic Process

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

Learning Outcomes

On the successful completion of the course the students should be ableto

- Plot a time series and interpret the components.
- Identify and estimate cyclical fluctuations in the time series.
- Examine the relationship between the lagged values of the series.
- Test for the stationarity of the series.
- Estimate ARIMA(p,d,q) model for the series.
- Define stochastic process and identify its type .
- Understand the concept of Markov chain and its basic properties using some theorems.
- Define and understand the concept and application martingale.
- Define Poisson process and understand its properties with some applications.
- Apply gamblers ruin problem for some problems.
- Understand the basic concept and applications of Weiner process, Renewal theory and branching process.

Section A

Time series as a stationary or non stationary stochastic process, Time domain analysis based on correlogram, Sample autocovariance function and autocorrelation function at lag K, Lag correlation. Measurement of cyclic fluctuations: Periodogram and its relation with acvf, Harmonic analysis. Measurement of irregular component: Variate difference method.

AR(p) process, MA(q) process, mixed ARMA(p, q) process, Stationarity and inevitability conditions, ARIMA (p, d, q) model, Estimation of parameters, Tests for stationarity Stochastic – Process.

Section B

Markov Chain having two states, n-step transition probabilities, Classification of states, Recurrent and transient states, Chapman-Kolmogorov equations, Stationary probability theorems and limit theorem for ergodic chains, Martingales.

Section C

Poisson process, birth and death process, Random walk and Gambler's Ruin problem, Wiener process, Renewal theory and its application, Branching chains: Discrete Process (Galton-Watson).

Suggested Books

1. Hoel, P. G., Port, S. C., & Stone, C. J. (1971). *Introduction to probability theory*, Universal Book Store, New Delhi.
2. Srinivasan, S. K., & Mehata, K. M. (1988). *Stochastic Processes*. New Delhi: Tata McGraw Hill.
3. J. Medhi, J. (1994). *Stochastic processes*. New Age International Publications.
4. Box, G. E. P., Jenkins, G. M., & Reinsel, G. C. (2008). *Time series analysis: Forecasting and control*. Hoboken: Wiley.
5. Chatfield, C. (1975). *The Analysis of Time Series: Theory and Practice*. Boston, MA: Springer US.

Suggested E-learning material

1. Lecture Notes and Videos on "Stochastic Hydrology": https://nptel.ac.in/courses/105108079/
2. Course material on "Time Series Analysis": http://hdl.handle.net/1721.1/46343
3. Lecture Notes on "Introduction to Stochastic Processes": https://ocw.mit.edu/courses/mathematics/18-445-introduction-to-stochastic-processes-spring-2015/lecture-notes/
4. Lecture Notes on "Discrete Stochastic Processes": https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-262-discrete-stochastic-processes-spring-2011/course-notes/

STAT 507Design of Experiments and Linear Models

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

Learning Outcomes:

After successful completion of this course, student will be able to:

- Identify what design was followed and its features, describe what assumptions are appropriate in modelling the data.
- Analyse the results of a designed experiment in order to conduct the appropriate statistical analysis of the data.
- Interpret statistical results from an experiment and report them in non-technical language.
- Compare efficiency of the experimental designs.

Section A

Estimable functions, estimation and error space, linear models and regression, Standard Gauss Markov Models, Best linear unbiased estimate (BLUE), Method of least squares, Variance covariance matrix of BLUEs, uses of g-inverse.

Section B

Analysis of variance, Completely randomized design (CRD), Randomised block design (RBD), Analysis of Covariance in CRD and RBD, 2^n Factorial Experiments, Complete and partial confounding, Split and Strip plot designs.

Section C

Balanced Incomplete Block Design (BIBD), Construction of BIBD, Intra block analysis, BIBD with recovery of interblock information. Balanced Incomplete Block Design (PBIBD), Analysis with two associate classes only.

Text Books:

1. Joshi, D. D. (1987). *Linear estimation and design of experiments*. New York: John Wiley.
2. Das, M. N., Das, M. N., & Giri, N. C. (2003). *Design and Analysis of Experiments*. New Delhi: New Age International (P) Ltd. Publishers.

Reference Books:

1. Rao, C. R. (2010). *Linear statistical inference and its applications*. New York : Wiley
2. Dey, A. (1988). *Theory of block designs*. New York: Wiley.
3. Giri, N. (1986). *Analysis of variance*. New Delhi: South Asian Publ.

Suggested E-learning material:

1. Lecture notes on Design of Experiments
   http://www.iasri.res.in/ebook/EB_SMAR/e-book_pdf%20files/Manual%20III/2-Basic%20Experiments.pdf
2. Lecture note on Split Plot Design http://www.iasri.res.in/design/analysis%20of%20data/split_plot_spss.html
3. Analysis of Data from Designed Experiments http://www.iasri.res.in/design/Analysis%20of%20data/Analysis%20of%20Data.html
4. Lecture notes on ANOVA
   home.iitk.ac.in/~shalab/anova/chapter4-anova-experimental-design-analysis.pdf

MATH536LComputational Lab – III

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Learning outcomes:

On completion of the course, the student will be able to,

- Analyze 2^n- factorial experiments.
- Apply ANCOVA with one and two concomitant variable
- Execute analysis and understanding of Split-plot designs and strip-plot design
- Appraise Narain, Horwitz-Thompson estimator, Des Raj's ordered estimator.
- Employ AR (p) process,MA (q) process, Mixed ARMA (p, q) process.

Design of Experiment and Linear Models.

1. Analysis of Completely randomized design (CRD) and Randomised block design (RBD).
2. 2-square factorial experiment.
3. 2- cube factorial experiment without confounding.
4. 2- cube factorial experiment with partial confounding.
5. 2- cube factorial experiment with complete confounding.
6. Split-plot designs
7. Strip plot designs.
8. ANCOVA with one concomitant variable.
9. ANCOVA with two concomitant variable.
10. BIBD

Survey sampling:

1. Estimation of mean and variance of sampling mean in cluster sampling.
2. Estimation of mean and variance using combined and separate ratio type estimators.
3. Estimation of population mean and total by ration and regression method of estimation.
4. Double sampling for ratio and regression methods of estimation.
5. Narain, Horwitz-Thompson estimator and its variance.
6. Des Raj's ordered estimator and the estimate of their variances.

Time Series and Stochastic Process:

1. Decomposition of time series.
2. Correlogram analysis.
3. Testing for stationarity.
4. Estimation of ARMA (p, q) process.
5. Estimation of ARIMA (p, d, q) model.

Suggested readings:

1. Lawson, J. (2014). *Design and Analysis of Experiments with R*. Chapman and Hall/CRC.
2. Book on Design of Experiment with R https://cran.r-project.org/doc/contrib/Vikneswaran-ED_companion.pdf
3. Statistics: An introduction using R http://www.agr.unideb.hu/~baloghp/Statistics/Crawley_Statistics_An

%20introduction%20using%20R/Statistics_Using%20R_2nd_Editio n.pdf

CS 209Data Structures

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

Learning Outcomes:

On successful completion of the course students will be able to

- Develop knowledge of basic data structures for storage and retrieval of ordered or unordered data. Data structures include: arrays, linked lists, stacks, queues, binary trees, heaps.
- Develop knowledge of applications of data structures including the ability to implement algorithms for the creation, insertion, deletion, searching, and sorting of each data structure.
- Learn to analyze and compare algorithms for efficiency using Big-O notation.
- Understand the concept of Dynamic memory management, data types, algorithms, Big O notation.
- Apply Algorithm for solving problems like sorting, searching, insertion and deletion of data

Section-A

Concept of data types, Abstract data type, Data structures, running time of a program, asymptotic notations: Big-Oh, Theta, Little-oh, Omega.

Linear data structures: Static implementation of stack, queue, and their applications

Searching and Sorting: Linear search and Binary Search, Bubble sort, Selection sort, Insertion sort, Quick sort, Radix sort.

Section-B

Linked List: Linear, doubly or two way, circular, header and various operations; Representation of polynomial using linked list, addition and subtraction of polynomials. Dynamic implementation of stacks and queues.

Dynamic memory management: fixed and variable block storage, storage techniques: first-fit, best-fit, worst-fit, next-fit; data compaction, and garbage collection.

Section-C

Non linear data structures: Tree concepts, General Tree, binary tree and types, binary search tree, implementation of various operations on Binary Search Tree (tree traversal, searching, insertion and deletion, counting leaf and non-leaf nodes, height).

Suggested Books:

1. Langsam, Y., Augenstein, M., & Tenenbaum, A. M. *Data Structures using C and C++*. PHI Learning, New Delhi.
2. Tremblay, J. P., & Sorenson, P. G. (1985). *An Introduction to Data Structures with Applications*. Tata McGraw-Hill.
2. Horowitz E. & S. Sahni (2009). *Fundamentals of Data Structures*. University Press.
3. A.V. Aho, J.E. Hopecraft & J.D. Ullman (1987). *Data Structures and Algorithms*. Addition –Wesley Publishing Co.
4. Lipschutz, Seymour. *Schaum's Outline of Theory and Problems of Data Structures*. Tata McGraw-Hill.

Suggested E-Learning Material:

1. Programming and Data Structures
   https://swayam.gov.in/course/1407-programming-and-data-structures
2. Data Structures and Program Methodology
   https://nptel.ac.in/courses/106103069/

CS 209L Data Structures Lab

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Lab Number	**Problems**
L1-L10	Programs based on static implementation of stacks and its application
L11-L18	Programs based on static implementation of queues (simple, circular, priority, dequeue) .
L19-L30	Operations on Singly, Doubly & Circular Linked lists. Dynamic implementation of stacks and queues.
L31-L40	Operations on Binary tree, binary search tree

MATH555Queueing Theory

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

Learning Outcomes:

On completion of the course, the 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 $M/M/\infty$ 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, NPTEL
   https://nptel.ac.in/courses/117103017/1
2. Introduction to stochastic process and applications, NPTEL
   https://nptel.ac.in/courses/110104024/1
3. Stochastic Process and Time series, ePATHSHALA
   https://epgp.inflibnet.ac.in/ahl.php?csrno=34

MATH546Inventory Theory

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

Learning Outcomes:

On completion of this course, students 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/

MATH539Fields and Galois Theory

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

Learning Outcomes:

On completion of this course, students 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/

STAT 508Distribution Theory

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

Learning Outcomes:

After successful completion of the course, the students 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 Edition.
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 material

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

CS 308Operating Systems

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

Learning Outcomes:

On successful completion of the course students will be able to

- Learn the fundamentals of Operating Systems.
- Learn the mechanisms of OS to handle processes and threads and their communication
- Learn the mechanisms involved in memory management in contemporary OS
- Gain knowledge on Mutual exclusion algorithms, deadlock detection algorithms and agreement protocols
- Know the components and management aspects of concurrency management
- Learn Case study of Unix OS.

Section-A

Operating system Functions, OS Goals, OS classification: single user, multiuser, Batch Processing Operating System, Time Sharing, Real Time Operating System (RTOS), Multiprogramming Operating System, Multiprocessing System, Networking Operating System, Operating Systems

for Embedded Devices, Introduction to popular operating systems like UNIX, DOS, Windows, etc.

Parallel processing and distributed processing: concept, differences, OS.

Process management: Process status, schedulers, scheduling algorithms

Inter process communication: Shared memory and message passing, Process Synchronization, Critical Section problem and its hardware, software and semaphore solutions, classical problems in concurrent programming.

Section-B

Memory management: partition, paging and segmentation demand paging, virtual memory, page replacement algorithms, thrashing.

Secondary storage: Disks, disk space management, Scheduling algorithms. Management file supports, access methods, allocation methods, contiguous, linked and indexed allocation, directory Systems I/O processor management: I/O traffic controller, I/O scheduler, I/O device handlers.

Section-C

Deadlock: Prevention, Avoidance, Detection and recovery. Protection and Security - Accessibility and Capability Lists UNIX: File System, Inode, Types of shells, Commands (basic, file mgmt, process mgmt, pipelines), vi editor, shell programming.

Suggested Books:

1. Silberschatz, A., Gagne, G., & Galvin, P. B. (2003). *Operating System Concepts* (6th ed.). Addision Wiley Publications.
2. Godbole, A. S. (1995). *Operating Systems with Case Studies in Unix, Netware, Windows NT*. Tata McGraw-Hill Education.
3. Kanetkar, Y. P. (1997). *Unix Shell Programming*. BPB Publications.
4. Tanenbaum, A. S. (2009). *Modern Operating System* (3rd ed.). Pearson Education.
5. Dietel, H. M.(2003). *Operating Systems* (2nd ed.). Pearson Education.

Suggested E-Learning Material:

1. Operating Systems
   https://nptel.ac.in/courses/106108101/
2. Linux for Developers by The Linux Foundation
   https://www.coursera.org/learn/linux-for-developers

CS 528Modeling and Simulation

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

Learning Outcomes:

On successful completion of the course students will be able to

- Define basic concepts in modeling and simulation (M&S).
- Classify various simulation models and give practical examples for each category.
- Construct a model for a given set of data and perform its validity.
- Generate and test random number and apply them to develop simulation models.
- Analyze output data produced by a model and test validity of the model.
- Explain parallel and distributed simulation methods.
- Know how to simulate any discrete system using queuing systems.

Section-A

Definition of system, system concepts, types of system. Continuous & discrete system, Models :- compartmental model, Iinear and nonlinear model, stochastic model, Verification & validation

Simulation: Introduction, classification of simulation models. Advantages & disadvantages of simulation. Discrete system simulation: Monte Carlo method, random no. generation, test of randomness, Probability Distributions and their random variates.

Section-B

Introduction to queuing theory: Queuing model with poison input, Exponential service & arbitrary service times, Simulation of queuing system, Simulation of single server queue; Simulation of two server queue, Application of queuing theory in computer system like operating system, computer network etc.

Introduction to inventory theory, EOQ Models, More complex inventory models.

Section-C

[Introduction of Simulation of system dynamics model]

Evaluation of simulation, length of simulation runs, Introduction to Variance reduction techniques.

Project management: Simulation of Pert /CPM technique

Models as component of information system *Modeling for decision support Virtual reality: ultimate interactive model.* [Simulation languages :- Simula. Dyanamo, Stella]

Simulation language:- Simula (Basic facts, History of Simula I and 67, Data types, Statements, Procedure, Classes and Packages)

Suggested Books:

1. Gordon, G. *System Simulation*. PHI Learning.
2. Deo, N. *System Simulation*. Tata Mcgraw-Hill.
3. Payne, J.A. *Introduction to Simulation.* Tata McGraw-Hill.
4. Law, A.M., Kelton W.D. *Simulation Modelling and Analysis.* Tata McGraw-Hill

Suggested E-Learning Material:

1. Modelling and Simulation of Descrete Event System
   https://nptel.ac.in/courses/112107220/
2. Simulation and modeling of natural processes by University of Geneva
   https://www.coursera.org/lecture/modeling-simulation-natural-processes/modeling-and-simulation-F7vas

CS 315Theory of Computation

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

Learning Outcomes:

On successful completion of the course students will be able to

- Explain basic concepts in formal language theory, grammars, automata theory, computability theory, and complexity theory.
- Understand abstract models of computing, including deterministic (DFA), non-deterministic (NFA), Push Down Automata(PDA) andTuring (TM) machine models and their power to recognize the languages.
- Understand the application of machine models and descriptors to compiler theory and parsing.
- Relate practical problems to languages, automata, computability, and complexity.
- Apply mathematical and formal techniques for solving problems in computer science.

- Understand the relationship among language classes and grammars with the help of Chomsky Hierarchy.

Section-A

Mathematical preliminaries, alphabets, strings, Languages, states, transitions, automata with & without output(Mealy & Moore machine) and regular expressions, applications e.g. Lexical analyzers and text editors, the pumping Lemma & closure property of regular sets, decision algorithms for regular sets.

Section-B

Context free grammars, Chomsky and Greibach normal form theorems, ambiguity, Pushdown automata and the equivalence of contex free languages to sets accepted by non-deterministic PDA, the Pumping Lemma for CFL's, closure properties of CFL's and decision algorithms for CFL's.

Section-C

Turing Machines: Introduction, Turing hypothesis, Turing computability, nondeterministic, multitape and other versions of Turing machine, Church's hypothesis, primitive recursive function, Godelization, recursively enumerable Languages and Turing Computability. Undecidability: Universal Turing machines and unsolvability of the halting problem, an undecidable problem, Post's Correspondence problem.

Suggested Books:

1. Hopcroft J.E. & Ullman J.D. (2002). *Introduction to Automata Theory, Languages and Computation* (1st ed.). Narosa Publishing House.
2. Mishra, K. L. P., & Chandrasekaran, N. (2006). *Theory of Computer Science: Automata, Languages and Computation*. PHI Learning, New Delhi.
3. Wood, D., (1987). *Theory of Computation* (1st ed.). Harper & Row Publishers, New York.
4. Lewis, H. R., & Papadimitriou, C. H. (2001). *Elements of the Theory of Computation* (1st ed.). Prentice Hall International Inc.

Suggested E-Learning Material:

1. Theory of Computation
   https://nptel.ac.in/courses/106104028/
2. An Introduction to Formal Languages and Automata by Peter Linz
   http://almuhammadi.com/sultan/books/Linz.5ed.pdf

MATH537Differential Geometry

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

Learning Outcomes:

On completion of the course, the student will be able to

- Compute Reparameterization, Curvature and Torsion of smooth curves of curves.
- Discuss about Osculating circle, Osculating sphere, Involutes and Evaluates, Bertrand curves, and Helices.
- Compute quantities of geometric interest such as curvature, as well as develop a facility to compute in various specialized systems, such as semi geodesic coordinates or ones representing asymptotic lines or principal curvatures.
- Develop arguments in the geometric description of curves and surfaces in order to establish basic properties of geodesics.

Section A

Curves in Plane and Space: Parameterized curves, Tangent vector, Arc length, Reparametrization, Regular curves, Curvature and Torsion of smooth curves, Frenet-Serretformulae, Osculating circle, Osculating sphere, Involutes and Evolutes, Bertrand curves, Spherical indicatrices, Helices.

Section B

Surfaces in R^3**:** Smooth surfaces, Tangent, Normal and Orientability. Examples of surfaces: Generalized cylinder and cone, ruled surfaces, Surface of revolution, First fundamental form, Isometries of surfaces, Conformal mapping of surfaces, Surface Area, Equiareal maps and Theorem of Archemedes, Second fundamental form, Curvature of curves on a surface, Normal and Principal curvatures, Meusnier's theorem, Euler's theorem, Classification of point on surface, Geometric interpretation of principal curvatures, Umbilical points.

Section C

Gaussian and Mean curvature, Pseudo sphere, Flat surfaces, Surfaces of constant mean curvature, Gaussian curvature of compact surfaces, Gauss map. Geodesics: Definition and basic properties, Geodesic equations, Geodesics on a surface of revolution, Clairaut's theorem, Geodesics as shortest paths, Geodesic coordinates, Geodesic curvature of a curve.

Suggested Text Book

1. Pressley, A. (2012). *Elementary differential geometry*. London: Springer.

Suggested Reference Books:

1. Carmo, M. P. (1980). *Differential geometry of curves and surfaces*. Englewood Cliffs, N.J: Prentice-Hall.
2. O'Neill, B. (2006). *Elementary differential geometry*. London: Elsevier/Academic Press.
3. Gray, A. (2000). *Modern differential geometry of curves and surfaces*. FL: CRC Press.
4. Somasundaram, D. (2010). *Differential geometry: A first course*. Harrow: Alpha Science International.

Suggested E-learning material:

1. NOC:Differential Calculus in Several Variables: https://nptel.ac.in/courses/111104092/
2. NOC:Curves and Surfaces: https://nptel.ac.in/courses/111104095/

MATH551Partial Differential Equations

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

Learning Outcomes:

On completion of the course, the student will be able to

- apply the techniques for solving partial differential equations.
- describe the most common partial differential equations that appear in problems concerning e.g. heat conduction, flow, elasticity and wave propagation
- solve simple first order equations using the method of characteristics and classify second order equations.
- describe, compute and analyse wave propagation and heat conduction in mathematical terms
- formulate maximum principles for various equations and derive consequences.
- evaluate and assess the results of various problems in other subjects based on these concepts.

Section A

Mathematical classification and Formulation of partial differential equations, Partial Differential equation of the first order, Lagrange's linear equation, different forms of non-linear partial differential equations, Charpit's method. Linear partial differential equations with constant coefficients. Homogeneous equations, Non-homogeneous equation.

Section B

Partial Differential equations of second order with variable coefficients, Monge's Methods, Separation of variables, The Wave equation (one and two dimensional) Fourier series solutions of the Wave equations (homogeneous and non-homogeneous), Numerical solution of the wave equation.

Section C

Heat equations (homogeneous and non-homogeneous), Numerical approximation of solution of standard heat condition problem, Harmonic Functions and Dirichlet Problem, Green's Functions and Properties. Existence theorem by Perron's Method.

Suggested Text Books:

1. John, F. (1991). *Partial differential equations*. New York: Springer.
2. Bansal, J. L., &Dhami, H. S. (2004). *Differential equations Vol II*. Jaipur: JPH.
3. O'Neil, P. V. (2012). *Advanced engineering mathematics*. India: Cengage Learning.
4. Sneddon, I. N. (1981). *Elements of partial differential equations*. New York McGraw-Hill.

Suggested References Books:

1. Weinberger, H. F. (1995). *A first course in partial differential equations with complex variables and transform methods*. New York: Dover Publications.
2. Williams, W. E. (1980). *Partial differential equations*. Oxford [Eng.] : New York : Clarendon Press ; Oxford University Press
3. Folland, G. B. (2003). *Introduction to partial differential equations*. New Delhi: Prentice Hall of India.
4. Rao, K. S. (2010). *Introduction to Partial differential equations*. New Delhi:Prentice Hall of India.

5. Amaranath, T. (2009). *An elementary course in partial differential equations*. Sudbury, Mass: Jones and Bartlett Publishers.
6. Sharma, J. N., & Singh, K. (2009). *Partial differential equations for engineers and scientists*. Oxford: Alpha Science International Ltd.

Suggested E-learning material:

1. Partial Differential Equation; Platform: https://ocw.mit.edu/courses/mathematics/18-02-multivariable-calculus-fall-2007/video-lectures/lecture-15-partial-differential-equations/
2. Introduction to partial differential equation; Platform: NPTEL https://nptel.ac.in/courses/111103021/
3. Video Lectures for Partial Differential Equations; Platform: LAMAR http://www.math.lamar.edu/faculty/maesumi/PDE1.html#pdeRESOURCES

STAT519Advanced Inference

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

Learning Outcomes:

After successful completion of this course, student will be able to

- Apply various estimation and testing procedures to deal with real life problems.
- Understand Fisher Information, Lower bounds to variance of estimators, MVUE.
- Understand consistency, CAN estimator, MLE.
- Understand Neyman-Pearson fundamental lemma, UMP test.
- Apply Likelihood Ratio test in real life testing problems.
- Understand invariant and similar test.

Section A

Consistency and asymptotic relative efficiency of estimators, Consistent asymptotic normal (CAN) estimator, Best asymptotic normal (BAN) for one parameter, Method of MLE and its large sample properties.

Section B

Generalized Neyman- Pearson lemma, UMP tests for distribution with monotone likelihood ratio (MLR), Unbiased tests, Similar regions and test of Neyman structure.

Section C

Invariance tests and UMP invariant tests, Likelihood ratio test. Consistency of Likelihood ratio test. Asymptotic properties of likelihood ratio test.

Text Books

1. Ferguson, T. S. (1996). *A course in large sample theory*. London, Chapman and Hill.
2. Goon, A. M., Gupta, M. K. & Gupta, B. D. (1973). *Fundamental of statistics* (vol. II), The World Press Pvt. Ltd.

Reference Books:

1. Gupta, A. D. (2008). *Asymptotic Theory of Statistics and Probability*. New York, Springer.
2. Kale, B. K. (1999). *A first course on parametric inference.* Narosa Publication.
3. Lehman, E. L. & Cesella, G. (1998). *Theory of Point estimation.*New York, Springer.
4. Rao, C. R. (1995). *Linear Statistical Inference and Its Applications.* Wiley Eastern Ltd.
5. Lehman, E. L. (1986). *Testing of point estimation*, John Wiley & Wiley Eastern.
6. Lehman, E. L.(1986).*Testing of Statistical Hypothesis*, John Wiley & Wiley eastern.

Suggested E-learning material

1. Statistical Inference, NPTEL
   https://nptel.ac.in/courses/111105043/
2. Statistical Inference, ePATHSHALA
   https://epgp.inflibnet.ac.in/ahl.php?csrno=34

STAT 502Bayesian and Multivariate Analysis

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

Learning Outcomes:

On the successful completion of the course, student will be able to,

- Find posterior distribution of a parameter.
- Identify the nature of the prior.

- Understand various types of loss functions and their nature.
- Use Bayesian theory to draw inferences in simple problems.
- Define multivariate normal distribution and understand its properties.
- Estimate the mean vector and covariance matrix of the multivariate normal population.
- Test the significance of single mean vector and difference in the two mean vectors.
- Perform PCA and factor analysis on real data set.
- Classify and discriminate the observations in two populations.
- Perform correlation analysis between two multivariate populations.

Section A

Bayes theorem for random variables. Prior and posterior distributions. Types of prior: non informative and improper priors for location, scale and location scale parameters.

Loss functions, decision rule and risk functions. Bayes estimation, Bayes principle, Bayes risk, Bayes test.

Section B

Multivariate Normal distribution marginal and conditional distributions, characteristics functions. Wishart distributions and its properties. Hotelling T^2, Mahalanobis D^2 and their applications.

Section C

Classification and discriminate analysis. Principal Component analysis. Canonical correlations and variables. Factor analysis.

Text Books :-

1. Berger, J. O. (2010). *Statistical decision theory and Bayesian analysis*. Springer, New York.
2. Anderson, T. W. (1958). *An introduction to multivariate analysis*. John Wiley & Wiley eastern.

Reference Books :-

1. Bernardo, J. M., & Smith, A. F. M. (2009). *Bayesian Theory*. John Wiley & Sons, Ltd.
2. Johnson, R. A., & Wichern, D. W. (2014). *Applied multivariate statistical analysis*. Pearson.

Suggested E-learning material:

1. Video lecture on 'Bayesian statistics without tears'
   https://podcasts.ox.ac.uk/bayesian-statistics-without-tears

STAT 502L Bayesian and Multivariate Analysis Lab

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Learning Outcomes

On completion of this course, the student will be able to

- Differentiate between the nature of prior and posterior densities by means of their plots
- Find Bayes estimator, Bayes Risk and perform Bayes testing
- Estimate mean vector and covariance matrix of given data set
- Perform testing of significance of single mean vector and difference of two mean vectors
- Reduce dimension of the data using principal component analysis and factor analysis
- Classify and discriminate observations in two or more populations
- Observe correlation between two sets of multivariate data sets.

1. Estimation of mean vector and co variance matrix.
2. Estimation and testing of partial and multiple correlation coefficients.
3. One sample and two sample problems using Hotelling T^2 statistics.
4. Problems based on Wishart distribution.
5. Exercise based on Mahalnobis-D^2.
6. Perform Principal Component Analysis, Factor Analysis
7. Exercises based on classification and discrimination
8. Finding Canonical Correlations between two data sets

Note :

(i) The above list is only for the guidance of the students. Any practical from the syllabus may be set in the practical examination.

(ii) Whenever it is feasible, students should be asked to collect the required data themselves to use it in their practicals.

(iii) Where it is feasible practical practice should be done through spreadsheet, package or programming.

Suggested Books

1. Marin, Jean-michel., & Robert, Christian. (2016). *Bayesian Essentials With R*. Springer-Verlag New York Inc.

2. Schumacker, R. E. (2016). *Using R with multivariate statistics*. Thousand Oaks, California: SAGE Publications, Inc.

Suggested E-learning Material

1. Using R for Multivariate Analysis
   https://little-book-of-r-for-multivariate-analysis.readthedocs.io/en/latest/src/multivariateanalysis.html

STAT 524Reliability and Renewal Theory

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

Learning Outcomes

On successful completion of the course, the students 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 andReliability*. UK: Pitman Publication.
3. Medhi, J. (2009). *Stochastic Process* (3rd Ed.). New Age International, 2009.

Suggested E-learning material:

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 516 Network Analysis and Goal Programming

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

Learning Outcomes:

On completion of this course, students will be able to:

- Plan and structure a project.
- Understand basic techniques for quality improvement,
- Apply the PERT & CPM techniques to optimize the project goals.
- Solve network models like the shortest path, minimum spanning tree, and maximum flow problems.
- Understand how to model and solve problems using Goal Programming

Section A

Flows in Network, Maximal Flow - Minimal Cut theorem using the concept of Duality, Maximal Flow problem, Feasibility theorems, General Minimal Cost Flow problem, Hitchcock problem, Bottleneck Assignment problem, Out-of-Kilter algorithm. Shortest path problem. Minimal spanning tree.

Section B

PERT & CPM: Critical path, Activity floats, Project crashing. Resource leveling and Resource scheduling.

Sequencing problem, Finite sequencing for a single machine, Flow shop and Job-shop problem, Sequencing with Stochastic processing times and parallel processing.

Section C

Goal Programming(GP): Introduction, Difference between LPP and GP, Formulation of Single goal with multiple subgoals. Equally ranked multiple goals, Ranking and weighting of unequal multiple goals. General goal Programming models. Graphical Solution of Models of Goal Programming, Modified simplex method, Alternative simplex method. Applications of Goal Programming.

Suggested Text Books:

1. Ahuja, R. K., Magnati,T. L. & Orlin, B. (1993).*Network flows: Theory, algorithm and applications,*Prentice Hall, New Jersey.
2. Bazaraa,M. S. &Jarvis, J. J. (1977). *Linear programming and network flows*(2nd Ed.). John Wiley New York.

Suggested Reference Books:

1. Ford,L. R.&Gulkerson, D. R. (1962)*Flows in networks*, Princeton University Press.
2. Conway, R. W., Maxwell, W. L., & Miller, L. W. (2012). *Theory of Scheduling*. Newburyport: Dover Publications.
3. French, S. (1990). *Sequencing and scheduling: An introduction to the mathematics of the Job-Shop*. New York: Horwood.
4. Moder, J. J., & Philips, C. R. (1970). *Project management with CPM and PERT*. New York: Van Nostrand.
5. Jensen, P. A., & Barnes, J. W. (1987). *Network flow programming*. Malabar, Fla: R.E. Krieger Pub. Co.
6. Panneerselvam, R. (2010). *Operations research*. New Delhi: PHI Learning.

Suggested E-learning material:

1. Critical path method (PDF)
   http://textofvideo.nptel.ac.in/112106131/lec34.pdf
2. Project Management(Video Lecture)
   https://nptel.ac.in/courses/110104073/21

MATH 516L Network Analysis and Goal Programming Lab

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Learning Outcomes:

On completion of the course, the student will be able to,

- Implement optimization methods in software to solve shortest path problem, spanning tree problem, programming problems etc.
- The science learning goals of laboratory experiences include enhancing mastery of science subject matter, developing scientific reasoning abilities, increasing understanding of the complexity and ambiguity of empirical work, developing practical skills, increasing understanding of the nature of science, cultivating interest in science and science learning.
- Write efficient, well-documented code and present numerical results in an informative way.

Practical/Lab to be performed on a computer using OR (TORA, LINGO, MATLAB etc.)/Statistical packages.

1. Determines the Flow of commodity in a network
2. Solution of Shortest path problem as a LPP
3. Shortest Path Problem using Dijkstra's algorithm
4. Problem based on Minimal Spanning Tree
5. Project planning (Deterministic case-CPM)
6. Project planning (Probabilistic case-PERT)
7. Problem based on Project management with Crashing
8. Solution of Flow Shop Problem
9. Solution of Job Shop Problem
10. To solve Goal Programming Problem using Graphical Method
11. Graphical solution of weighted Goal programming
12. Graphical solution of pre-emptive Goal programming
13. Solution of Goal Programming Problem with simplex method

Text Books/ Reference Books:

1. Winston, W. L. (2009). *Operations research: Applications and algorithms*. Belmont, Calif: Brooks/Cole, Cengage Learning.
2. Hillier, F. S., & Lieberman, G. J. (2016). *Introduction to Operations Research*. Boston: McGraw-Hill.

Suggested E-learning material:

3. Optimization Toolbox
   https://in.mathworks.com/help/optim/index.html
4. LINGO
   http://swmath.org/software/4942

CS 213Design and Analysis of Algorithms

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

Learning Outcomes:

On successful completion of the course students will be able to

- Analyze the performance of various algorithms in terms of time and space.
- Solve recurrence relation using various methods.
- Compute complexity of various iterative and recursive algorithm.
- Understand the concept and design algorithm using data structures including threaded binary tree, B-Tree and hashing techniques.
- Understand numerous algorithm design techniques including divide& conquer, greedy, dynamic programming, backtracking and branch& bound.
- Choose appropriate algorithm design techniques for solving real world problems.
- Understand how the choice of the algorithm design methods impact the performance of programs

Section-A

Analysis of an algorithm, Time and Space complexity, Asymptotic notation to represent complexity of an algorithm, Recurrences- substitution method, iteration method and master method.

Advance Data Structures: Threaded Tree, B-Tree, Heap and Heap Sort, Union and Find operations on Disjoint Set, Hashing, Representation of Graph and Breadth First & Depth First Traversal of Graph.

Section-B

Divide and Conquer: General method, Max-Min, Binary Search, Merge Sort, Quick Sort, and Matrix Multiplication.

Greedy Technique: General Method, Knapsack Problem, Job Sequencing, Optimal Merge Patterns, Minimum Spanning Tree, Single Source Shortest Path.

Dynamic Programming: General Method, 0/1 Knapsack Problem, Traveling Salesman Problem.

Section-C

Backtracking: General Method, N Queen Problem, Sum of Subsets Problem, Graph Coloring Problem, 0/1 Knapsack Problem.

Branch and Bound: General Method, 0/1 Knapsack Problem, Traveling Salesman Problem,

NP Hard & NP Complete Problems: Basic Concepts, Deterministic & Non Deterministic Polynomial Time Algorithms, Tractability, Examples of NP Hard & NP Complete Problems.

Suggested Books:

1. Horowitz, E., & Sahni, S., & Rajasekaran, S. (2008). Fundamentals of Computer Algorithms (2nd ed.). University Press.
2. Knuth, D. E. (1997). *The Art of Computer Programming v.1. Fundamental algorithms (3rd ed.)*, Pearson Education.
3. Cormen, T. H., Leiserson, C. E., Rivest, R. L., & Stein, C. (2001). *Introduction to Algorithms* (2nd ed.). MIT Press.
4. Berman, K.A., & Paul, J.L. (2002). *Algorithms.* Cengage Learning
5. Basu, S.K. (2005). *Design and Analysis of Algorithm,* PHI Learning.

Suggested E-Learning Material:

1. Design and Analysis of Algorithms
   https://nptel.ac.in/courses/106101060/
2. Algorithms Specialization by Stanford University
   https://www.coursera.org/specializations/algorithms
3. Introduction to Algorithms by Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest and Clifford Stein
   https://mcdtu.files.wordpress.com/2017/03/introduction-to-algorithms-3rd-edition-sep-2010.pdf

CS 213LDesign and Analysis of Algorithms Lab

Max. Marks : 100	**L**	**T**	**P**	**C**
(CA: 40 + ESA: 60)	**0**	**0**	**4**	**2**

Lab No. **Problems**

L1- L5 Implementation of Max Heap (Creation, Insertion, Sorting), Operations on Sets (Creation, Union, Weighted Union, Find and Collapsing find)

L6-L8 Implementation of Threaded Binary Search Tree (Creation, Insertion, Traversal, Searching, Find successor and predecessor of a given node)

L9-L12 Implementation of B Tree (Creation, Searching, Insertion)

L13-L15 Implementation of Divide and Conquer Algorithms (Merge-Sort and Matrix Multiplications)

L16-L20 Implementation of Greedy Knapsack problem, job sequencing with Deadline and Minimum spanning tree algorithms (Prims and Kruskal)

L21-L23 Implementation of Signal source shortcut path Algorithms, DFS and BFS Algorithms.

L24-L30 Implementation of N-Queens, Sun of Subset, Graph Coloring, 0/1 Knapsack Problem and Traveling Salesman Problem.

CS 313Software Engineering

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

Learning Outcomes:

On successful completion of the course students will be able to

- Understand the system development lifecycle.
- Understand the software-development process, including requirements analysis, design, programming, testing and maintenance.
- Model object-oriented software systems.
- Investigate and improve the specification of a software system.
- Specify, design and construct CASE tools and application software.
- Develop and apply testing strategies for software applications.
- Identify some of the main risks of software development and use.
- Effectively participate in team-based activities.

Section-A

Software engineering concepts, historical perspective, software evaluation, program design paradigms. Software project planning: identifying software scope, resources, Feasibility study, cost/benefit analysis, information gathering, analysis concept, analysis modeling (behavioral model, data model, functional model), Need & Role of System Analyst.

analysis tools & techniques, risk management, project scheduling, tracking. Cost estimation : project metrics, cost factors, cost estimation techniques (decomposition, empirical, automated estimation, delphi)

Section-B

System design : Design concepts & principles (modularization, abstraction, refinement, cohesion, coupling) design methods (structured design, database design, user interface design, object oriented design, real time system design), Implementation : modern programming language features & characteristics, language classes, coding style, efficiency.

Section-C

Software Quality Assurance : Risk management, Quality factors and criteria, SQA metrics, SQA techniques. Verification and Validation : software testing methods (WBT, BBT), software testing strategy (Unit testing, integration testing, validation system, testing), System Implementation/conversion: Direct, parallel, Pilot, phased. Maintenance: Maintenance characteristics, Maintainability, software reuse, re-engineering, reverse engineering, CASE.

Suggested Books:

1. Pressman, R. S. (1997). *Software Engineering: a practitioner's approach* (4th ed.). Tata McGraw-Hill.
2. Jalote, P. (2003). *An Integrated approach to Software Engineering*, Narosa Publications.
3. Awad, E. M., *Systems Analysis and Design* (2nd ed.). Galgotia Publications.
4. Rajaraman, V. *Analysis and Design of Information Systems* (2nd ed.). PHI Learning, New Delhi.
5. Fairley, R. (1997). *Software Engineering Concepts*. Tata McGraw-Hill.
6. Mall, R. (2004). *Fundamentals of Software Engineering*. PHI Learning, New Delhi.
7. Sommerville, I. (2008). *Software Engineering*. Pearson Education.

Suggested E-Learning Material:

1. Software Engineering
   https://nptel.ac.in/courses/106101061/
2. Software Engineering by Roger S. Pressman
   http://qiau.ac.ir/teacher/files/911610/13-11-1387-17-31-03.pdf

Discipline Elective

MATH 501 Advanced Analysis (Analysis on Abstract Spaces)

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

Learning Outcomes:

On completion of this course, students will be able to

- Explain when Normed space become Banach space.
- Define the Hilbert spaces.
- Define multi linear mappings.
- Check whether the function is bounded or not?
- What is directional derivative?
- Explain the difference between partial derivative and directional derivative.
- Tell about the Lipschitz's constant and conditions
- Related 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 continuous functions, Stone-Weierstrass Approximation Theorem equicontinuous 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

Differential Equations: First order differential equations approximate solutions, Lipschitz's property, dependence on the initial value, dependence on a parameter, linear differential equations.

Suggested Text Book:

1. Dieudonne, Jean A. (1969). *Treatise on analysis*: *Foundations of modem analysis (*Vol. I). New York: Academic Press.

Suggested Reference Books:

1. Cartan, H. (1983). *Differential calculus*.London: Kershaw Publishing.
2. Hewitt, E. J., & Stromberg, K. R. (1975). *Real and abstract analysis: A modern treatment of the theory of functions of a real variable*. New York: Springer-Verlag.
3. Yosida, K. (1968). *Functional analysis*. (2nd Ed.). New York, N.Y: Springer-Verlag.

Suggested E-learning Material:

1. Normed space Banach space and Hilbert spaces and its properties; Platform:

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

MATH 503 Advanced Functional Analysis

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

Learning Outcomes:

On completion of this course, students will be able to

- Check whether a sequence of operators convergence or divergences?
- Explain how continuous function on a closed and bounded interval can be uniformly approximated on that interval by polynomials to any degree of accuracy.
- Explain how you will apply the Banach fixed point theorem.
- Relate the fixed point with solution of differential and Integral equation.
- Check the spectral properties of bounded linear operators
- Check whether the operator is compact or not?
- Explain and use of the properties of compact linear operators.

Section A

Convergence of sequence of operators and functions, Toeplitz limit theorem, Weierstass approximation theorem for polynomials, Baire's Category theorem, Banach fixed point theorem, Application of Banach fixed point theorem to linear equations, Differential equations, Integral equations (Fredholms integral equation of second kind).

Section B

Spectral theory in finite dimensional normed spaces, Spectral properties of bounded linear operators, further properties of Resolvent & Spectral, Use of complex Analysis in Spectral theory, Banach Algebras.

Section C

Compact linear operators and their properties, Spectral properties of compact linear operation, further Spectral properties of compact linear operators, Operator equations involving compact linear operators, further theorem onFredholm type, Fredholm Alternative.

Suggested Books:

1. Kreyszig, E. (2008). *Introductory functional analysis with applications*. New York: Wiley.
2. Bachman, G., &Narici, L. (2012). *Functional Analysis*. New York: Dover Publications.
3. Rudin, W. (2006). *Functional analysis*. New York: McGraw-Hill.
4. Limaye, B. V. (2014). *Functional analysis*. (3rd Ed.). New Delhi: New Age International (P) Limited.
5. Goffman, C., &Pedrick, G. (2002). *First course in functional analysis*. New Delhi: Prentice Hall of India.

Suggested E-learning material:

1. Lectures: Platform: NPTEL

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

MATH 504 Analytic and Algebraic Number Theory

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

Learning Outcomes:

On completion of this course, students 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 510 Integral Equations and Calculus of Variations

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Acquire ability to recognize difference between Volterra and Fredholm Integral Equations, First kind and Second kind, homogeneous and inhomogeneous.
- Identify different types of integral equations and apply these methods to solve Integral Equations.
- Understand of the fundamental concepts of the space of admissible variations and concepts of a weak and a strong relative minimum of an integral.
- Solve isoperimetric problems of standard type.
- Solve simple initial and boundary value problems by using several variable calculus.

Section A

Linear Integral Equations: Definition and classification. Conversion of initial and boundary value problems to an integral equation, Eigevalues and eigenfunctions. Solution of homogeneous and general Fredholm integral equations of second kind wih separable kernels, Symmetric kernels, Resolvent kernel. Solution of Fredholm ad Volterra integral questions of second kind by method of successive substitutions and successive approximations. Solution of Voltera integral equations with convolution type kernels by Laplace transform, Green's function, Construction of Green’s function.

Section B

Conditions of uniform convergence and uniqueness of series solution, Complex Hilbert space, Orthogonal system of functions, Fundamental properties of eigen values and eigen functions for symmetric kernels, expansion in eigen functions and bilinear form, Hilbert Schmidt theorem, Solution of Fredholm integral equations of by using Hilbert Schmidt theorem, Classical Fredholm theory:Fredholmfirst fundamental theorem and its applications.

Section C

Variation of a functional, Fundamental lemma of calculus of variation, Euler-Lagrange equation, Necessary and Sufficient conditions for extrema., Variational problems for functional: Brachitochrone problem, problem of geodesics, Isoperimetric problem. Functionals dependent on higher order derivatives, Fields of Extremals: Proper field and Central field, Application of Euler-ostrogrdasky equations, rayleigh - ritz method for solution of partial differential equations.

Suggested Text Books:

1. Gelfand, I. M., &Fomin, S. V. (1965). *Calculus of variations*. Englewood Cliffs, N.J: Prentice-Hall.
2. Gupta, A. S. (2015). *Calculus of variations with applications*. New Delhi : Prentice Hall India.
3. Raisinghania, M. D. (2007). *Integral Equations and boundary values problems*. New Delhli: S. Chand & Company.

Suggested Reference Books :

1. Corduneanu, C. (2008). *Integral equations and applications*. Cambridge: Cambridge University Press.
2. Hildebrand, F. B. (1992). *Methods of applied mathematics: Second edition*. New York, N.Y: Dover.
3. Tricomi, F.G. (1985). *Integral equations*, New York:Dover.

Suggested E-learning material

1. Open course in Integral equations, calculus of variation and its applications (all Topics)

   https://nptel.ac.in/courses/111107103/
2. Volterra and Fredholm Integral Equations:

   http://staff.ul.ie/mitchells/Final_notes.pdf
3. Green's Functions

   http://www.maths.manchester.ac.uk/~wparnell/MT34032/34032_Int Equns.pdf

4. Neumann series, resolvent kernels and variational problem
   https://swayam.gov.in/courses/4824-july-2018-integral-equations-calculus-of-variations-and-its-applicati
5. Open course in integral equations:
   https://ocw.mit.edu/courses/mathematics/18-307-integral-equations-spring-2006/

MATH 517 Number Theory and Cryptography

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Understand the basic concepts of number theorem and their applications in cryptography.
- Know the need of security of digital data.
- Demonstrate the application of mathematics in computer science.
- Appreciate the historical cryptosystems and the development of modern cryptography.
- Demonstrate the knowledge of mathematics behind RSA cryptosystem, ElGamal Cryptosystem and secrete sharing schemes.

Section A

Divisibility, greatest common divisor, Euclidean algorithm,Extended Euclid's algorithm, linear congruences, Chinese remainder theorem, prime numbers, Fermat's theorem, Euler's Theorem, primitive root and indices, quadratic residues, Legendre symbols, quadratic reciprocity law, Jacobi symbols, finite fields,arithmetic in finite fields,time estimates for basic arithmetic operations.

Section B

Introduction to cryptography, classical cryptosystems and their cryptanalysis, perfect secrecy, Stream cipher and Block cipher, LFSR, DES, pseudo random bit generators, public key cryptography, one way and trapdoor functions, discrete logarithm problem, Deffie-Hellman key exchange protocol, integer factorization problem and primility testing.

Section C

Public key encryption: RSA, Rabin, El-Gamal, knapsacks; hash functions, Digital signatures: RSA, El-Gamal, DSA, Entity Authentication, Zero knowledge protocols, Shamir secret sharing schemes.

Suggested 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/

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:

On completion of the course, the 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: Birkhauser.
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 529 Theory of Games

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

Learning Outcomes:

On completion of the course, the student will be able to,

- understand all the basic concepts and results ofgame theory.
- understand terms like Nash equilibrium, the extensive form (which computer scientists call game trees), Bayesian games (modelling things like auctions), repeated and dynamic games.
- recognize and model strategic situations, to predict when and how your actions will influence the decisions of others and to exploit strategic situations for your own benefit.

- understant the game theoretic tools for modelling and solving problems in operations management.

Section A

Fundamental theorem of Rectangular Zero-sum games, Properties of Strategies, Relation of Dominance, Methods of solving Rectangular Zero-sum games.

Section B

Games with infinitely many strategies. The fundamental theorem of continuous games, differential Games, Separable games with convex pay-off function.

Section C

Solution of n-persons games with and without zero-sum restriction. Lanchester's equations and their application to games of strategy. Stochastic Games.

Suggested Books:

1. Myerson, R. B. (2013). *Game Theory: Analysis of Conflict*. Cumberland: Harvard University Press.
2. Levin, R. I., &DesJardins, R. B. (1970). *Theory of games and strategies*. Scranton, Pa: International Textbook Co.
3. Luce, R. D., &Raiffa, H. (1989). *Games and decisions: Introduction and critical survey*. New York: Dover.
4. McKinsey, J. C. C. (2006). *Introduction to the theory of game*. Mineola, N.Y: Dover Publications.
5. William, J. D. (1966).*The complete strategist*, New York: McGraw Hill.

Suggested E-learning material:

1. Game Theory: Lecture notes(PDF)

   https://ocw.mit.edu/courses/economics/14-126-game-theory-spring-2016/
2. Game Theory and Economics: Lecture notes(PDF)

   https://nptel.ac.in/courses/109103021/

MATH 530 Viscous Fluid Dynamics

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Understand the fundamental concepts of fluid dynamics.
- Derive the fundamental equations governing the flow of a viscous fluid.
- Demonstrate the analytical solutions of navier-stokes equations by making certain assumptions for certain geometries.
- Identify, formulate and solve engineering problems.

Section A

Viscosity, Analysis of stress and rate of strain, stoke's law of friction, Thermal conductivity and generalized law of heat conduction, Equation of state and continuity, Navier-Stokes equations of motion, Vorticity and circulation, Dynamical similarity, Inspection and dimensional analysis, Non-dimensional parameters and their physical importance: Reynolds number, Froude number, Mach number, Prandtal number, Grashoff number, Brinkmann number, Non-dimensional coefficients: Lift and drag coefficients, skin friction, Nusselt number.

Section B

Exact solutions of Navier-Stokes equations, Velocity distribution for plane Couette flow, plane poiseuille flow, Generalized plane Couette flow, Hagen - Poiseuille flow, Flow in tubes of uniform cross-sections, Flow between two concentric rotating cylinders.

Section C

Stagnation point flows- Hiemenz flow, Homann flow. Flow due to rotating disc. Concept of unsteady flow, Flow due to plane wall suddenly set in the motion. (Stoke's first problem), Flow due to an oscillating plane wall (Stoke's second problem), Starting flow in a plane Couette motion. Suction/injection through porous walls.

Suggested Books:

1. Bansal, J. L. (2005). *Viscous fluid dynamics* (2nd ed.). New Delhi: Oxford & IBH publishing Co.
2. Yuan, S.W. (1988). *Foundations of fluid mechanics*. New Delhi: Prentice-Hall of India.

3. Schlichting, H., &Gersten, K. (2000). *Boundary layer theory* (8th ed.). Springer, India.

Suggested E-learning material

1. Viscous Fluid Flow, Platform: The University of Manchester;
   http://www.maths.man.ac.uk/~mheil/Lectures/Fluids/index.html
2. Fluid Mechanics, Platform: nptel;
   https://nptel.ac.in/courses/112105171/
3. Introduction to Fluid Mechanics and Fluid Engineering, Platform: FreeVideoLectures;
   https://freevideolectures.com/course/3513/introduction-to-fluid-mechanics-and-fluid-engineering/28

MATH 507 Financial Mathematics

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

Learning Outcomes:

On completion of the course, the 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 513 Marketing Management

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

Learning Outcomes:

On completion of the course, the 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.
- Understand the concept of promotional decisions in the presence of competition.
- Use game theory models for promotional effort.
- Make channels of distribution and transportation decision.

Section A

Concept of Marketing and its role in Business and Public Organization, Marketing Decisions, Need for Scientific Marketing Analysis, uses and Limitations of Mathematical models in Marketing, Classification of Marketing Structure depending upon the nature of competitive conditions, Consumer behavior.

Demand elasticity's, Elasticity theorems, Joint optimization of price, quality and promotional effort Purchasing under Fluctuating prices.

Section B

Factors affecting Pricing decision, Pricing methods. Promotional decisions in the presence of competition, Game theory Models for Promotional Effort, Spatial Allocation of Promotional effort, media Allocation of advertisement, Brand Switching Analysis.

Section C

Sales response to Advertising in Presence of Competition. Channels of distribution, Transportation decision, Locating company's wholesale dealers and warehouses.

Case studies relating to marketing decisions.

Suggested Text Books:

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.

Suggested Reference Books:

1. Lilien, G. L., Kotler, P., & Moorthy, K. S. (2009). *Marketing models*. Prentice Hall of India.
2. King, W. R. (1967). *Quantitative analysis for marketing management*. New York: McGraw-Hill.

MATH 543Fuzzy Logic and Belief Theory

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

Learning Outcomes:

On successful completion of this course students 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 and 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.
- formulate logical expressions, fuzzy logic to solve a variety of problems related to real scenarios
- 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-01%20Introduction.pdf

MATH 534Coding Theory

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

Learning Outcomes:

On successful completion of this course students 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 540Fixed Point Theory

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

Learning Outcomes:

On successful completion of this course students 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

Metric spacescomplete 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. Istratescu, 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.

Suggested E-learning material:

1. National Programme for Technology Enhanced Learning (NPTL) [https://nptel.ac.in/courses/111105037/]

MATH 545Introduction to Dynamical Systems

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

Learning Outcomes:

On successful completion of this course students will be able to:

- Describe the main features of dynamical systems and their realization 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 Lyapunor 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 R^2, Linear 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 533Bio Mathematics

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

Learning Outcomes:

On completion of the course, the 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 analyze 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 532Algebraic Topology

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Generate original solutions to a variety of mathematical problems related to the fundamental group and covering spaces.
- Recall all definitions and theorems in this course and use them to construct original proofs and/or counterexamples, even on demand (e.g. in exams or discussions).
- Use algebraic invariants of topological spaces to distinguish spaces which otherwise seem similar.
- Apply computational algorithms to compute algebraic invariants of simple topological spaces.

Section A

Homotopy, Straight line homotopy, Null homotopy. Contractible spaces and Homotopy type. Retract, Deformation Retract and Strong Deformation Retract. No-Retraction theorem. Fundamental Group and its properties. The Degree map, path homotopy, homotopy class. Simply connected spaces.

Section B

Calculation of Fundamental Groups of Circle, The Cylinder, The Torus, the Punctured Plane And the n-sphere $\mathbf{S^n}$. Brouwer's Fixed-Point Theorem for the Discs, The Fundamental Theorem of Algebra. Covering projections, Properties of covering projection.

Section C

The Path Lifting Property, Homotopy Lifting Property, Applications of Homotopy Lifting Theorem, The Monodromy Theorem. The Right Action of the fundamental group. Lifting of an arbitrary map. Lifting theorem. Covering homomorphism. Group of Deck transformation. Universal covering space, The Covering theorem.

Borsuk-Ulam theorem.

Suggested Text books:

1. Deo, Satya. 2003. *Algebraic topology: a primer*. New Delhi: Hindustan Book Agency.
2. Munkres, J. R. (1978). *Topology, a first course*. New Delhi: Prentice-Hall of India.

Suggested Reference books:

1. Singh, T. B. (2013). *Elements of topology*. CRC Press.
2. Hatcher, Allen. 2002. *Algebraic topology*. New York: Cambridge University Press.
3. Bredon, Glen E. 2006. *Topology and geometry*. New York: Springer.

Suggested E-learning material

1. Algebraic Topology; Platform: NPTEL https://nptel.ac.in/courses/111101002/

MATH 535Combinatorial Optimization

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

Learning Outcomes:

On completion of the course, the 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., (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 559Transportation System Analysis

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

Learning Outcomes:

On completion of the course, the student will be able to,

1. Use optimal transportation decision-making schemes based on transportation data analysis by establishing, testing and solving transportation models.
2. Perform simple statistical analysis on transportation field data, sample estimation and hypothesis testing in transportation system.
3. 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., (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.

MATH 544Integral Transform and Special Functions

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

Learning Outcomes:

On completion of the course, the student will be able to,

- understand transformations, and their conditions of existence.
- carry out integraltransformations and inverse transformation of different special functions, including some 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 integral transformations.
- discuss the nature of special functions in different domains.

Section A

Laplace Transform: Definition, Transform of some elementary functions, rules of manipulation of Laplace Transform, Transform of Derivatives, relation involving Integrals, the error function, Transform of Bessel functions, Periodic functions, convolution of two functions, Inverse Laplace Transform of simple function, Tauberian Theorems. Applications of Laplace Transform to solve ordinary differential equations with constant and variable coefficients, initial and boundary value problems.

Section B

Fourier series, Fourier integral Theorem, Fourier Transform, Fourier Cosine Transform, Fourier Sine Transform, Transforms of Derivatives, Fourier transforms of simple Functions, Fourier transforms of Rational Functions, Convolution Integral, Parseval's Theorem for Cosine and Sine Transforms, Inversion Theorem, Solution of Partial Differential Equations by means of Fourier Transforms. Mellin transform, Properties, Mellin transform of derivatives and integrals, Mellin inversion theorem, Convolution theorem.

Section C

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, Hypergeometric differential equations

Legendre polynomials: Solution of Legendre's Equation, Generating function, Rodrigue's formula, Orthogonal properties. Integrals involving Legendre polynomials, Recurrence relations, Legendre's function of second kind $Q_n(x)$. Bessel functions, solutions of Bessel's equation, Generating function, Integral expressions. Recurrence relations, orthogonal properties.

Suggested Text Books:

1. Sneddon, I.N. (1974). *The use of integral transforms*, New Delhi: Tata McGraw Hill.
2. Rainville, E. D. (1960). *Special functions*, New York:Chelsea Publishing Company.

Suggested References:

1. Davies, B. (1978). *Integral transforms and their applications*, New York:Springer.

2. Slater, L. J. (2008). *Generalized hypergeometric functions*. Cambridge: Cambridge University Press.
3. Mathai, A. M., &Haubold, H. J. (2011). *Special functions for applied scientists*. New York: Springer.

Suggested E-learning material

1. Advanced Engineering Mathematics; NPTL: https://nptel.ac.in/courses/111105035/22

STAT 505 Decision Theory

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

Learning Outcomes

On completion of the course, the 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 material:

1. Decision Theory; platform:

   http://www.utdallas.edu/~mbaron/7330/

STAT 522Econometric Models

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

Learning Outcomes:

After a successful completion of this course students 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 Material:

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 504 Clinical Trials

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

Learning Outcomes:

After reviewing this paper, students should 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 material

1. Clinical Trials

   http://www.esourceresearch.org/eSourceBook/ClinicalTrials/1LearningObjectives/tabid/192/Default.aspx

2. Clinical Trials as Research

https://newonlinecourses.science.psu.edu/stat509/node/6/

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 successful completion of this course, student will be able to,

- Solve hypothesis testing problems where the conditions for the traditionalparametric 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, Mc Nemar 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 Resources

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:

On the successful completion of the course the students should be ableto

- 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, R^2 and adjusted R^2. 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 material:

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 515 Statistical Computing

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

Learning Outcomes:

After successful completion of this course, student will be able to:

- Simulate and generate statistical data by different techniques.
- Understand the basic concepts of statistical theories besides developing their ability tohandle real world problems with large scale data.

Section A

Review of R, 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.

Section B

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

Section C

Bayesian posterior density estimation, Monte Carlo EM, Univariate Density estimation and smoothing: Histogram method, Kernel smoothing method. Multivariate density estimation, an introduction to functional data analysis.

Text Books:

1. GIvens, H.G. & Hoeting, J.A. (2013). *Computational Statistics*, (2nd Ed.), Wiley.
2. Robert, C. & Casella, G. (2004). *Monte Carlo Statistical Methods*, Springer Publication.

Reference Books:

1. Law, A. M. & Kelton, W.D. (2000). *Simulation, Modelling and Analysis* (3rd Ed). Tata McGraw Hill.
2. Thisted, R.A. (1988). *Elements of Statistical Computing*, Chapman and Hall.
3. Lee, P. M. (2004). *Bayesian Statistics: An Introduction*, 3rd ed. London: Arnold.

4. Robert, C. & Casella, G. (2009). *Introducing Monte Carlo Methods with R*, Springer Verlag.

Suggested E-learning material

1. Statistical computing Platform: MITOPENCOURSEWARE https://ocw.mit.edu/index.htm
2. Statistics: Platform: e-PG Pathshala
   https://epgp.inflibnet.ac.in
3. Exploratory Data analysis ; Platform: Coursera https://www.coursera.org
   https://ocw.mit.edu/index.htm

STAT 527Stochastic Models

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

Learning Outcomes:

After successful completion of this course, the students 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 Material:

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 521Demography

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

Course Outcomes:

After successful completion of this course, the students 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 completenessof registration data; Adjustment of age data- use of Whipple, Myer and UN indices; Population transitiontheory.

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 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: MITOPENCOURSEWARE
   https://ocw.mit.edu/index.htm

STAT 518Actuarial Statistics

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

Course Outcomes:

After successful completion of this course, the students will be able to:

- Understand the applications of Actuarial Statistics in insurance sector.
- Understand the concept of utility theory and premium principles.
- Construct life tables with various factors.
- Understand the concept of compound interest.
- Apply various life Insurance models in real life situations.

Section A

Actuarial science: an overview, Introductory Statistics and Insurance Applications: Discrete, continuous and mixed probability distributions, risk and insurance, insurance products, reinsurance and its different types. Utility theory: Utility functions, expected value principle, expected utility criterion, types of utility function, insurance and utility theory. Principles of Premium Calculation: Properties of premium principles.

Section B

Survival Distribution and Life Tables: Age at death random variable, survival function, time until-death for a person, curate future lifetime, force of mortality, life tables, relation of life table functions to the survival

function, deterministic and random survivorship group, life table characteristics, recursion formulas, assumptions for fractional age, analytical laws of mortality, select and ultimate tables.

Section C

Principles of compound interest: Nominal and effective rates of interest and discount, force of interest and discount, compound interest, accumulation factor, continuous compounding, present value of a future payment. Life Insurance models: Models for insurance payable at the moment of death and at the end of the year of death - level benefit insurance, endowment insurance, deferred insurance and varying benefit insurance.

Suggested Books:

1. Dickson, C. M. D. (2005). *Insurance Risk and Ruin (International Series no. 1 Actuarial Science),* Cambridge University Press.
2. Bowers, N.L., Gerber, H.U., Hickman, J.C., Jones, D.A. and Nesbitt, C.J. (1997). *Actuarial Mathematics.* Society of Actuaries, Itasca, Illinois, U.S.A.
3. Rotar, V.I. (2015). *Actuarial Models: The Mathematics of Insurance*, 2nd ed., CRC Press, New York.
4. Deshmukh, S.R. (2009). *Actuarial Statistics: An Introduction Using R*, University Press, India.

Suggested E-learning material

1. Winkel, M. (2003). Actuarial Science
   http://www.stats.ox.ac.uk/~winkel/o13.pdf

STAT 528Survival Analysis

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

Learning Outcomes:

On completion of the course, the 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 one-sample and two-sample analyses of survival data using common statistical procedures such as the log rank test and Kaplan-Meier estimator
- Formulate research questions involving survival data as regression problems
- Fit the proportional hazards regression and parametric regression models 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
- Understand and use methods for analyzing correlated survival data
- Interpret and critically evaluate survival analyses in biomedical or epidemiologic manuscripts

Section A

Characteristics of survival data and problems, censoring and its types, likelihood and inference of life distributions, relationship between the survival function, distribution function, hazard function, relative hazard, and cumulative hazard, univariate analyses of survival data using the Kaplan-Meier estimator and actuarial estimator, estimation under the assumption of IFR/DFR, tests of exponentiality against non-parametric classes, total time on test.

Section B

Two-sample analyses of survival data using common statistical procedures such as the log rank test and Gehan test, Parametric and semi-parametric regression model to survival data and assess the estimation, scientific significance, precision, and interpretation of regression coefficients, graphical and other methods to assess the adequacy of fitted models and propose alternate solutions when common assumptions are violated,

Section C

Time-dependent covariates in the proportional hazards model and estimate and interpret the coefficients, methods for analyzing correlated survival data, Competing risk model: parametric and non-parametric inference for this model.

Text Books

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.

Reference Books

1. Breslow, N. and Day, N. (1987). *Statistical Methods in Cancer Research, v. 2: The Design and Analysis of Cohort Studies*. Lyon: IARC.
2. Therneau T, and Grambsch, P. (2000). *Modeling Survival Data: Extending the Cox Model*. New York: Springer
3. Kalbfleish, JD. and Prentice, RL. (2002). *The Statistical Analysis of Failure Time Data*. New York: Wiley.

Suggested E-learning material

1. Lecture Notes on Introduction to Survival Analysis: http://www.stat.columbia.edu/~madigan/W2025/notes/survival.pdf

CS 419 Distributed Computing

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

Learning Outcomes:

On successful completion of the course students will be able to

- Study software components of distributed computing systems. Know about the communication and interconnection architecture of multiple computer systems.
- Recognize the inherent difficulties that arise due to distributed-ness of computing resources.
- Understand the hardware and software concepts of distributed operating systems, various design issues like transparency, flexibility etc., and communication and synchronization in distributed operating systems.
- Understand scheduling in distributed operating systems, fault tolerance, real-time distributed systems, and designing of distributed file systems.

- Understand the concept of design and implementation in the context of distributed operating systems.
- Develop various synchronous and asynchronous algorithms: Leader election, shortest path problem, minimal spanning tress, randomized co-ordinated attack problem, consensus problems and construction of the breath first tree, spanning tree, and maximal independent set.
- Have in-depth knowledge of asynchronous shared memory model including various classical algorithms of mutual exclusion and resource allocation.

Section-A

Distributed Operating System : Distributed Computing system models, Issues in design of distributed operating system, message passing, Remote Procedure Calls, synchronization, process management, resource management, distributed file systems.

Section-B

Distributed Algorithms : Introduction to distributed algorithms, synchronous and partial synchronous models, Algorithms in general synchronous leader election (LCR Algorithm, HS Algorithm, A Simple Flooding Algorithm) , Breadth first search, shortest path, Minimum Spanning Tree, Maximal Independent Set, Distributed consensus with link and process failures. Asynchronous system model, I/O automata, operation of automata, complexity measures, randomizations.

Section-C

Asynchronous shared memory model, mutual exclusion (Dijkstra Mutual Exclusion Algorithm, Lockout-free Mutual Exclusion Algorithm, An algorithm using Single-Writer Shared Register, Bakery Algorithm), resource allocation (Dining Philosophers Problem, Right-Left Dining Philosophers Algorithm, Randomized Dining Philosopher Algorithm), Consensus, Asynchronous network model (Send/Receive Systems, Broadcast Systems, Multicast Systems), basic asynchronous network algorithms, shared memory Vs Networks.

Suggested Books:

1. Sinha, P. K. (2002). *Distributed Operating Systems: Concepts and Design*. PHI Learning.
2. Tanenbaum, A. S. (2009). *Distributed Operating Systems*. Pearson Education .

3. Lynch, N. A. (2009). *Distributed Algorithms* (3rd ed.). Morgan Kaufmann Publications.
4. Rumelhart D.F, McClelland JI & PDP Group (1999). *Parallel Distributed Processing,* vol I&II, MIT Press.
5. Dony, R. D., & Haykin, S. (1999). *Neural Network Approaches to Image Compression* (2nd ed.). IEEE Press.

Suggested E-Learning Material:

1. Distributed Systems
   https://nptel.ac.in/courses/106106168/
2. Distributed Systems by Maarten van Steen
   https://www.distributed-systems.net/index.php/books/distributed-systems-3rd-edition-2017/

CS 427 Parallel Computing

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

Learning Outcomes:

On successful completion of the course students will be able to

- Develop computer program for different type of parallel computers.
- Measure the performance of algorithm used and parallel computers.
- Solve problem using parallel computers.
- Optimize sequential code to parallel code and determine if they are worthwhile to parallelize. Develop, analyze and implement algorithm for parallel computers with shared memory and with distributed memory.
- Analyze and perform development work related to use of parallel computers and are able to get placement in the govt. organization.

Section-A

Introduction to parallel computing, advantages of parallel computing. Solving problems in parallel : Temporal parallelism, Data parallelism and their comparison. Intertask dependency and task graphs. Structures of parallel computers : Pipelined paprallel computers, Array processors, Shared memory multi-processor, message passing multiprocesors, MMC systems. Integer Arithmetic : Carry look-ahead addition and carry-save addition on binary tree, integer multiplication and convolution on a linear array. Elementary sorting algorithm.

Section-B

Matrix Algorithms : Matrix-Vector multiplication and solving lower triangular system of equations on a linear array, matrix multiplication, LU decomposition, matrix inversion, Gaussian elimination on a mesh.

Graph Algorithms : Mesh algorithm for transitive closure, connected component, shortest path, breadth first search and minimum spanning tree. Mesh of trees and its applications such as Matrix-Vector multiplication, Convolution and integer multiplication.

Section-C

More fancier networks : r-dimensional mesh of trees, shuffle trees, shuffle-exchange network, hypercube, De-bruijn network and butterfly. Some examples on these networks, sorting and FFT on butterfly.

Introduction to dataflow computers. Parallelism in logic programming.

Programming parallel computers.

Suggested Books:

1. Rajaraman, V. (1990). *Elements of Parallel Processing*. PHI Learning.
2. Quinn, M. J. (1978). *Designing Efficient Algorithms for Parallel Computers*. Tata McGraw-Hill.
3. Lakshmivaraha, S., & Dhall, S. K. (1990). *Analysis and Design of Parallel Algorithms: Arithmetic and Matrix Problems*. Tata McGraw-Hill, Inc.

Suggested E-Learning Material:

1. Parallel Computing

   https://nptel.ac.in/courses/106102114/

CS 431 Real Time Systems

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

Learning Outcomes:

On successful completion of the course students will be able to

- Explain fundamental principles for programming of real time systems with time and resource limitations.
- Describe the foundation for programming languages developed for real time programming.

- Account for how real time operating systems are designed and functions.
- Describe what a real time network is.
- Use real time system programming languages and real time operating systems for real time applications.
- Analyze real time systems with regard to keeping time and resource restrictions.

Section-A

Introduction to Real-time computing: Characterizing Real-time system & tasks; Performance measures of real time systems, estimation of program run time, Real-time system design: Hardware requirement, system-development cycle, data transfer techniques, synchronous & asynchronous data communication, standard interfaces.

Section-B

Task Assignment and Scheduling: Priority scheduling, scheduling with fixed priority dynamic priority scheduling, Real-time programming languages & Tool: desired language characteristics, data typing, control structure, run time error handling, overloading & generics, run time support, Real-time databases.

Section-C

Real time communication algorithms, Fault tolerence techniques: Causes of failure, fault types, fault detection, redundancy, integrated failure handling Reliability Evaluation techniques: Parameter values, reliability model for hardware redundancy, software error model, Clock synchronization.

Suggested Books:

1. Krishna, C.M., & Shen, K.G. (1997). *Real Time Systems*. Tata McGraw-Hill.
2. Liu Jane W.S. (2000). *Real Time Systems*, Pearson Education.
3. Laplante, P. A. (1997). *Real Time Systems Design Analysis* (2nd ed.). PHI Learning.

Suggested E-Learning Material:

1. Real-Time Systems by Jan Jonsson
   http://www.cse.chalmers.se/edu/year/2015/course/EDA222_Real_Time_Systems/Documents/Slides/
2. Fault Tolerance by Yandex
   https://www.coursera.org/lecture/big-data-essentials/fault-tolerance-rcwk5

CS 433 Soft Computing

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

Learning Outcomes:

On successful completion of the course students will be able to

- Develop NN network based application.
- Differentiate between supervised, unsupervised and reinforcement learning.
- Apply fuzzy logic on real life problems.
- Design Hybrid Systems vizNeuro-Fuzzy, Neuro- Genetic, Fuzzy-Genetic systems.

Section-A

Neural Network(NN) Paradigms : Introduction, Neuron model, Neural network architectures, Learning Rules (Hebbian, Competitive, Baltzmann, Supervised, unsupervised) Types of neural networks : Perceptron, MLP, radial basis function network, recurrent network, self organizing Feature maps, Boltzamann m/c, Applications of NN.

Section-B

Fuzzy Logic : Introduction, Fuzzy sets, Basic operations on fuzzy sets, relations, rule based models and linguistic variables, fuzzy control, interpolation in fuzzy rule base, Applications of Fuzzy logic.

Section-C

Evolutionary Computations : Introduction, Genetic Algorithm(GA), Evolutionary programming, Classifier systems, genetic programming parse trees, Mathematical foundation of GA variants of GA (hybrid GA, Fuzzy GA Enhancements of genetic programming, application).

Suggested Books:

1. Haykin, S. (2009). *Neural Networks: A Comprehensive Foundation*. Pearson Education.
2. Klir, G. J., & Yuan, B. (2010). *Fuzzy Sets and Fuzzy Logic: Theory and Applications*. PHI Learning.
3. Goldberg, D. E. (2007).*Genetic Algorithms in Search Optimization and Machine Learning.* Pearson Education.

4. Jang, J. S. R. (2003). *Neuro-Fuzzy and Soft Computing; A Computational Approach to Learning and Machine Intelligence*. PHI Learning.
5. Freeman, J. A. (2002). *Algorithms, Applications, and Programming Techniques*. Pearson Education.
6. Bart, K. (2003). *Neural Networks and Fuzzy Systems: A Dynamical Systems Approach to Machine Intelligence*. PHI Learning.
7. Li, H. (1995). *Fuzzy Logic and Intelligent Systems*. Kluwer Academic.
8. Zimmermann, H. J. (1996). *Fuzzy Set Theory and Applications*. Allied Publishers.
9. Driankov, D. (1996). *An Introduction to Fuzzy Control*. Narosa.
10. Mitchell, M. (1996). *An Introduction to Genetic Algorithms*. PHI Learning.
11. Rajasekaran, S.,& Pai, G. V. (2003). Neural Networks, Fuzzy Logic and *Genetic Algorithms: Synthesis and Applications*. PHI Learning.
12. Yegnanarayana, B. (2003). *Artificial Neural Networks*. PHI Learning.

Suggested E-Learning Material:

1. Neuro-Fuzzy and Soft Computing by University of Southampton
   http://www.cs.nthu.edu.tw/~jang/nfsc.htm
2. Introduction to Soft Computing
   https://nptel.ac.in/courses/106105173/
3. Neural Networks and Deep Learning by Andrew Ng
   https://www.coursera.org/courses?query=neural%20networks

CS 507 Artificial Intelligence

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

Section-A

Introduction to Artificial Intelligence, General problem solving, state space and graph model techniques, Heuristic designs, Aim-oriented heuristic algorithms versus solution guaranteed algorithms, Game playing strategies.

Knowledge Representation : Knowledge representation tools, First order predicate calculus. Understanding Logic Programming Using PROLOG. Semantic Nets, Frames, production rules, knowledge base, the inference system, forward and backward deduction.

Section-B

Cognitive Computing: Introduction, Elements of Cognitive Systems. Understanding Complex Relationships Between Systems. Understanding Cognition. Transformation of Artificial Intelligence into Cognitive Computing Systems. Uses of Cognitive Computing Systems. System of Judgment and Choice. Designing a Cognitive System. Graining Insight from Data. Bringing Data into Cognitive System. Defining Objective. Defining Domain. Understanding the Intended Users and Defining their Attributes. Defining Questions and Exploring Insights. Creating and Refining the Corpora. Training and Testing.Understanding Natural Language, Parsing techniques, context free and transformational grammar, transition net, augmented transition nets, Fillmore's grammar, Shanks conceptual dependency. Grammar free analysers, Sentence generation, Translation.

Section-C

Enabling Reasoning in Cognitive Systems Through Probabilistic Learning: Bayesian Networks, Approximate Inference, Constructing Bayesian Networks. Markov Chains, Hidden Markov Model: Forward Algorithm, Viterbi Algorithm, Baum-Welch Algorithm.Application of Cognitive Computing: Enhancing the Shopping Experience. Leveraging the Connected World of Internet of Things. Voice of the Computer. Fraud Detection. Case Study of Cognitive Computing Systems.

Suggested Books:

1. Russell, S. J., & Norvig, P. (2013). *Artificial Intelligence: A Modern Approach* (3rd ed.).PHI Learning.
2. Vernon, D. (2014). Artificial Cognitive Systems: A Primer. MIT Press.
3. Rich, E., & Knight, K. (2011). *Artificial Intelligence* (3rd ed.). Tata McGraw-Hill.
4. Patterson, D. W. (1990). *Introduction to Artificial Intelligence and Expert Systems*. PHI Learning.
5. Barr, A., Cohen, P. R., & Feigenbaum, E. A. (1982). *The Handbook of Artificial Intelligence*. Addison-Wesley.

6. Allen, J. (1995). *Natural Language Understanding* (2nd ed.). Pearson Education India.
7. Nilsson N.J., (1991). *Principles of Artificial Intelligence*. Narosa Publishing.
8. Nilsson, N. J. (1998). *Artificial intelligence: A New Synthesis*. Morgan Kaufmann Inc.
9. Luger, G. F. (2002). *Artificial intelligence: Structures and Strategies for Complex Problem Solving*. Addison-Wesley.
10. Charniak E., & McDermott D. (1985). *Introduction to Artificial Intelligence*. Addison-Wesley.

Suggested E-Learning Material:

1. Artificial Intelligence by IIT Kharagpur
   https://nptel.ac.in/courses/106105077/
2. Artificial Intelligence: Principles and Techniques by Stanford University
   https://web.stanford.edu/class/cs221/

CS 527 Mobile Computing

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

Learning Outcomes:

On successful completion of the course students will be able to

- Have knowledge of fundamentals of mobile communication systems.
- Choose system (TDMA/FDMA/CDMA) according to the complexity, installation cost, speed of transmission, channel properties etc.
- Identify the requirements of mobile communication as compared to static communication.
- Identify the limitations of 2G and 2.5G wireless mobile communication and use design of 3G and beyond mobile communication systems.

Section A

Introduction to Wireless Communication System : Evolution, Generations (1G, 2G, 2.5G, 3G), Wireless Transmission : Frequencies, ISM, Signals, Antennas; Signal propagation effects; Comparison of Wireless

Communication Systems : Land-Mobile technologies (GSM, CDMA), Satellite Communication, In building Communication Systems, Personal Communication Systems.

Cellular Concept : Basics & Traffic concepts, System Capacity, Trunking theory & GoS, Improving coverage & capacity - Frequency reuse. Cell Splitting/Sectoring, Umbrella cell, Breathing cell

Section B

Wireless MAC protocols : S/F/T/CDMA, CSMA protocols, MACAW, Spread Spectrum : DSSS, FHSS; WWAN (GSM : Mobile services, System Architecture, Radio Interface, Protocols, Localization & Calling, Handover, Security, New Data Services; CDMA); WLAN (IEEE 802.11 : System architecture, Protocol architecture, MAC Management; H1PERLAN : Introduction), Mobile IP, MANET : Routing protocols, DHCP, Unicast & Multicast Communication; Wireless TCP; WPAN : Blue tooth, IEEE 802.15 (Introduction)

Section C

Mobile Computing: Challenges, Issues; Location & Data Management; Power management, Power-aware & Context-aware computing, Support for Mobility : WAP

Introduction to Pervasive Computing - Applications, Devices, Software; Mobile Computing Software development : Strategies & Tools

Suggested Books:

1. Schiller, J. H. *Mobile Communications*(2nd ed.). Pearson Education.
2. Stojmenovic, I. (2003). *Handbook of Wireless Networks and Mobile Computing*. John Wiley & Sons.
3. Rappaport, T. S. *Wireless Communications: Principles and Practice* (2nd ed.). PHI Learning.
4. Williams, V. *Wireless Computing Primer*. M & T Books.
5. Pandya, R. (1994). *Mobile and Personal Communication Systems and Services*. PHI Learning.
6. Hansmann, U., Merk, L., Nicklous, &M.S., Stober. *Pervasive Computing HandBook*. Springer.
7. Perkins, C. E., Alpert, S. R., & Woolf, B. (1998). *Mobile IP: Design Principles and Practices*. PHI Learning.
8. Garg, V. K. & Wilkis, J. E. (1996). *Wireless and Personal Communication*. PHI Learning.

9. Muller, N. J. (2001). *Bluetooth Demystified*. Tata McGraw-Hill.
10. Sturman, C. F., & Bray, J. *Bluetooth: Connect without Cables* (2nd ed.). Pearson Education.
11. Dhawan, C. (1997). Mobile Computing: A Systems Integrator's Handbook.Tata Mc-Graw-Hill

Suggested E-Learning Material:

1. Wireless Communications by Stanford University
   https://web.stanford.edu/class/ee359/
2. Data Communications II by University of Massachusetts Lowell
   http://mobile.cs.uml.edu/~glchen/cs414-564/handouts/

CS 523 Emerging Programming Paradigms

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

Section A

Visual Computing: Windows program architecture, procedural and event oriented languages, GUI components, controls, control arrays, file processing, database connectivity (ADO, DAO, RDO), Multiple Document Interface (MDI), OLE, report generation, multimedia, concept of MFC library.

(Visual programming to be done using VB).

World Wide Web (WWW) and Web Programming: Web documents, web server and browsers, HTTP protocol, HTML and its features, embedding images, audio and video, web designing and publishing, web designing tools.

Section B

Java Programming: Java program architecture and its features, Java Virtual Machine (JVM) and Java Development Kit(JDK), applets and applications, variables, data types and control constructs in Java, classes and objects in Java, inheritance, interfaces and packages. standard Java packages, string, vector, multithreading, exception handling, GUI components, GUI layout management, animation and handling images.

Section C

Advanced Java Programming: Streams and I/O programming, network programming, concept of serialization, Javaswings, Javaservlet, Java Beans, RMI and Introduction to COBRA.

Advanced Web Based Programming: static and dynamic web page, DHTML, scripting languages (VB script, Java script), Server side programming and database interfacing (JDBC,ODBC), Active Server Pages (ASP), concept of XML and UML.

Sugessted Reference Books :-

1. John Zukowski, Mastering Java-2.
2. Evangelos Petroutsos, Mastering Visual Basic-6.
3. Deborah S. Roy, Eric J. Roy, Mastering HTML 4.0.
4. Deital & Deital, Java How To Program.
5. A. Russel Jones, Mastering Active Server Page 3.0, BPB publication.
6. Ann Navaro, Mastering XML, BPB publication.
7. Wendy Boggs and Michael Boggs, Mastering UML with Rational Rose, BPB publication.

ELE 304 Digital Signal Processing

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

Section A

Introduction of Signals, Systems and Signal Processing, Classification of Signals and Systems, Advantages of Digital Over Analog Singnal processing, Signal Models – Continuous Time versus Discrete time signals, Periodic and Aperiodic Signals, Phasor Signals and Spectra, Energy and Power Signals, System Modeling Concepts, The superposition integral for Fixed and Linear Systems, Impulse Response of a Fixed and Linear System - Fourier Series - Trigonometric Series - Exponential Fourier Series-Symmetry Properties of the Fourier Coefficients.

Fourier Integral, Energy Spectral Density, Fourier Transforms in the Limit, Fourier Transform Theorems and Pairs, System Analysis with Fourier Transform, Laplace Transform Theorems, Network Analysis using the Laplace Transform.

Section B

Discrete Time Signals and Systems - Review of Sampled Data Systems, Time Domain Representations of Discrete Time Signals, Frequency Domain Representation of Discrete Time Signals, Discrete Time Signals obtained by sampling, Discrete Fourier Transform. Z-Transform - Definition and Examples, Inverse Z-Transform, Properties of the Z-Transform, Introduction to Realization of Digital Systems - Block

Diagrams and Signal Flow Graphs. Introduction to Realization of an IIR and FIR systems, Discrete Fourier Transforms (DFT) and Fast Fourier Transform (FFT).

Section C

Design of Digital Filters: Introduction to Filters, A comparision of IIR and FIR Digital Filters.Design of IIR Digital Filters - Impulse Invariant Transformation, Bilinear Transformation, Design of Digital Butterworth and Chebyshev Filters.Design of FIR Digital Filters - Windowing and Rectangular Window, Filter Designs using Windows, Frequency Sampling Technique. DSP tools and DSP techniques in various applications.

Sugessted Text/Reference Books:

1. Alan V. Oppenheim, Ronald W. Schafer, **Digital Signal Processing**, Prentice Hall of India.
2. J. Defatta, **Digital Signal Processing**, John Willey & Sons.
3. Prokians, **Digital Signal Processing**, PHI.

CS 510 Client-Server Computing and Applications

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

Learning Outcomes:

On successful completion of the course students will be able to

- Understand real life application using client-server architecture.
- Learn concepts of network and its usage in client-server model.
- Design distributed database for various application.

Section A

Evolution of PC, Introduction to Local Area Networks, PC LANS, Mainframe computers, PC connected to mainframes.

Section B

Distributed systems and database. Client-Server computing model, client-server hardware and software needs, issues in client server computing-shared access, connectivity, security. Advantages of client-server computing. Exmaples: UNIX and Windows NT.

Section C

Client-server applications: Database server networks, gateways, video-conferencing and multimedia applications. Client server architectures: segmentation, switched FDDI, peer to peer architecture.

Suggested Books:

1. Dewire, D. T. *Client Server Computing* (1st ed.). Tata McGraw-Hill.
2. Berson, A. *Client Server Architecture*. Tata McGraw-Hill.
3. Orfali, R., Harkey, D., & Edwards, J. (2007). *Client Server Survival Guide* (3rd ed.). John Wiley & Sons.
4. Trivedi, M., Khanna, M. *Client Server Computing*. Book Publishing Co. Pvt. Ltd.

Reading Elective I & II

MATH547RNetwork Biology

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Understand the use of graph theory in biology
- Build and analyse network of biological systems.

Networks in Biology, Graph Theory, Global Network Properties, Network Centralities, Network of Clustering, Network Motifs, Petri Nets, Signal Transduction and Gene Regulation Networks, Protein Interaction Networks, Metabolic Networks, Phylogenetic Networks, Ecological networks, Correlation Network, Network Construction.

Suggested Readings:

1. Junker, B. H., & Schreiber F. (2008).*Analysis of Biological Networks,*John Wiley & Sons, Inc.
2. Zhang, W. (2013).*Network Biology Theories, Methods and Applications,* Nova Science Publishers, Inc.

MATH541RFractional Calculus

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Understand fractional integrals of some important functions
- Understand the concepts of Fractional Derivatives
- Carry out research on the topic related to fractional calculus

Origin, Significant contributions, development in different timelines, different aspects, contributors in the field, The Riemann Liouville Fractional Calculus: Fractional Integrals of some functions namely binomial function, exponential, the hyperbolic and trigonometric functions, Bessel's functions, Hyper-geometric function. Dirichlet's Formula, Derivatives of the Fractional Integral and the Fractional Integral of Derivatives. Laplace Transform of the Fractional integral, Leibniz's Formula for Fractional Integrals. Derivatives, Leibniz's Formula of Fractional Derivatives.

Suggested Readings:

1. Oldham, K.B. & Spanier, J. (2006). The *Fractional Calculus: Theory and Applications of Differentiation and Integration to Arbitrary Order*. Dover Publications Inc.
2. Machado, J.T.A., Virginia, K., & Mainardi, F. (2011). Recent History of Fractional Calculus. *Communications in Nonlinear Science and Numerical Simulation*.
3. Machado, J. A. T., Kiryakova , V. & Mainardi, F. (2010). A poster about the recent history of fractional calculus. *J. Fractional Calculus and Applied Analysis.*

MATH554RQuantum Graphs

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Describe some basic tools in the spectral theory of Schrödinger operator on metric graphs

- Demonstrate results on the count of zeros of the eigen functions of quantum graphs.

Demonstrate key concepts of general spectral theory.

Introduction, Operators on graphs, Quantum Graphs, Quantum Graphs: Some Special topics, Spectra of quantum graphs, Spectra of periodic graphs, Quantum Chaos on graphs, Some Applications and generalizations. The Spectral Form Factor for Quantum Graphs with Spin-Orbit Coupling, Approximation of Permutation-Symmetric Vertex Couplings in Quantum Graphs, Determinant of the Schrodinger Operator on a Metric Graphs, Laplacian or Metric Graphs; eigenvalues, resolvents and Semigroups.

Suggested Readings:

1. Berkolaiko G. and Kuchment Peter (2016), *Introduction to Quantum Graphs*, Indian Edition.
2. Berkolaiko G., Carlson R., Fulling S. A. and Kuchment Peter (2006), *Quantum Graphs and Their Applications*, American Mathematical Society.

MATH552RPoint Set Topology

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Express the notion of metric space, construct the topology by using the metric and using this topology identify the continuity of the functions which are defined between metric spaces.
- Define the notion of topology; construct various topologies on a general set which is not empty by using different kinds of techniques.
- Define the subspace topology, Construct the product topology on product spaces, and Construct the quotient topology.

Sets, Functions, The Real Numbers, Zorn's Lemma, Countable Sets, Metric Spaces, Sequences and completeness, Continuity, Compactness, Connectedness, The Baire Category Theorem, Topological Spaces, Base and Subbase for a Topology, Continuous Functions, Compactness and Connectedness, Pathwise connectedness, Infinite Products, Nets , Quotient Topology.

Suggested Readings:

1. Conway, J. B. (2014). *A course in point set topology*. Springer.
2. Körner, T. (2010). Metric and topological spaces.
3. Munkres, J. R. (1978). *Topology, a first course*. New Delhi: Prentice-Hall of India.

MATH549ROperational Research Applications

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

Learning Outcomes:

On completion of the course, the student will be able to,

- To have the knowledge of role of O.R. in solving industrial problems.
- To introduce the important ideas in operations research which are both fundamental and long lasting.
- To prepare and motivate future specialists to continue in their study by having an insightful overview of operations research.
- To demonstrate the cohesiveness of operations research methodology.
- To identify the resources required for a project and generate a plan and work schedule.

Media allocation problem, Cargo Loading Problem, Production Scheduling Problem, Wood cutting problem, School bus routing problem using spanning tree, Simulation, Knapsack problem, Set Covering Problem, Fixed Charge Transportation Problem, Project Selection Problem.

Suggested Readings:

1. Taha, H. A. (2010). *Operations Research-An Introduction* (9th Ed.), Prentice Hall.
2. Winston, W. L., & Venkataramanan, M. (2002). *Introduction to Mathematical Programming: Applications and Algorithms* (4th ed.). Duxbury Press.
3. Ravindran, A., Phillips, D. T. & Solberg, J. J. (2005). *Operations Research. Principles and Practice*, John Wiley & Sons.
4. Hadley, G. (1964). *Nonlinear and Dynamic Programming*, Addison-Wesley.

STAT525RSelected Applications of Stochastic Models

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Elucidate the power of stochastic processes and their range of applications.
- Demonstrate essential stochastic modelling tools including Markov chains and queuing theory.
- Use probabilistic arguments including conditional distributions and expectations.
- Carry out basic modelling using Markov chains in discrete and continuous time.
- Review and apply Markov chains methods based on stationary and asymptotic distributions.

Markov decision processes: finite and infinite horizon models. Optimality of Markov policies. Computational aspects. Examples from inventory systems, resource allocation, etc.

Learning algorithms: Temporal difference methods. Methods based on approximation functions; TD(lambda); Q-learning. Stability of queuing models. Little's law and its extensions. Advanced queuing models in discrete and continuous time.

Some classes of stochastic scheduling rules; minimizing mean sum of completion times on a single machine with and without pre-emptions and index policies. Makespan with and without pre-emptions on parallel machines; due date related objectives.

Suggested Readings:

1. Bertsekas, D. P. (1995). *Dynamic programming and optimal control* (Vol. 1 & 2). Belmont: Athena publications.
2. Wolff, R.W. (1989). *Stochastic modeling and theory of queues*. Englewood Cliffs: Prentice-Hall Inc.
3. Pinedo, M. (1995). *Scheduling: Theory, algorithms and systems*. Englewood Cliffs: Prentice-Hall Inc.

STAT526RStep-Stress Modelling

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

Learning Outcomes:

On completion of the course, the student will be able to,

- Understand statistical models and methods for analyzing accelerated life-test data from step-stress tests.
- Understand how to use ALT methods in real life problems.

Deferent Aspects of ALT Models, Accelerated Life Test, Step Stress Test, Acceleration Model, Cumulative Exposure Model, Optimum Step-Stress Accelerated Life Test Models, Optimum Step-Stress Partially Accelerated Life Test Plans with Type-I and Type-II Censoring.

Suggested Readings

1. Kundu, D. and Ganguly, A. (2017). *Analysis of Step-Stress Models*. Elsevier.
2. Tang, L-C. (2018). *Multiple-steps Step-stress Accelerated Life Test*. Springer.
3. Accelerated Life Test; Platform: http://home.iitk.ac.in/~kundu/seminar25.pdf
4. Different aspects of ALT models; Platform: https://www.worldscientific.com/doi/pdf/10.1142/9789813141261_fmatter

STAT520RCategorical Data Analysis

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

Learning Outcomes:

On completing the course, the student will be able to:

- Identify and understand the structure of categorical data and be able to phrase the appropriate scientific questions in terms of parameters of interest.
- Understand the various assumptions needed for the various methodologies
- Test for independence, and equality of proportions

- Fit logistic models for binary data
- Check model assumptions and analyze residuals and goodness-of-fit
- Conduct inference for model parameters and interpret the output of the models

Categorical Response Data: Nominal/Ordinal scale, statistical inference for a proportion and discrete data. Probability Structures for Contingency Tables. Comparing Proportions in Two-by-Two Tables, Odds Ratio: their properties and relation with relative risk. Tests of Independence of two attributes. Testing Independence for Ordinal Data: Choice of Scores, Trend Tests for $I \times 2$ and $2 \times J$ Tables, Nominal–Ordinal Tables, Exact Inference for Small Samples. Association in Three-Way Tables.

Logistic regression model: Interpretations, inferences, model selection, model checking. Logit Models for Nominal Responses, Cumulative Logit Models for Ordinal Responses, Paired-Category Ordinal Logits. Loglinear Models for Two-Way and Three-Way Tables

Suggested Readings

1. Alan Agresti, An Introduction to Categorical Data Analysis, Second Edition, Wiley Interscience, 2007.
2. Categorical Data Analysis: http://web.pdx.edu/~newsomj/cdaclass/

STAT531RRobust estimation in Non Linear Models

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

Learning outcomes:

On completion of this course, student will be able to

- Understand the basics of fitting and inference for nonlinear regression methods when the regression function acting on the predictors is not linear in the parameters.
- Check the robustness of the fitted model
- Carry out research in the area of robust estimation

Non Linear Models: Introduction to non Linear models, non-linear least squares estimators, outliers, robustness of models against outliers, robust M-estimation approach, asymptotic properties of robust M-estimators, the asymptotic theoretical properties of M-estimators under different

possibilities of the M-estimation function and noise distribution assumptions.

It is an important and challenging problem to design robust order estimation techniques for nonlinear nested models and establish their asymptotic optimality properties

Suggested readings:

1. Cizek, P. (2001).Robust Estimation in Nonlinear Regression Models. https://www.researchgate.net/publication/23737960_Robust_Estimation_in_Nonlinear_Regression_Models
2. Zhu, L., Li, R., & Cui, H. (2013). Robust estimation for partially linear models with large-dimensional covariates. *Science China. Mathematics*, *56*(10), 2069–2088. https://doi.org/10.1007/s11425-013-4675-0
3. Neugebauer, S.P. (1996). Robust Analysis of M-Estimators of Nonlinear Models. *citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.11.2523&rep=rep1...pdf*

STAT530ROfficial Statistics

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

Learning Outcomes:

On completion of the course, the students will be able to:

- Know the key aspects of Official Statistics, as distinct from other branches of statistics.
- Know the legal and ethical constraints on organizations producing Official Statistics.
- Know the principal methods for data collection, analysis and interpretation of health, social and economic.
- Know the methods for presenting and preparing commentaries on Official Statistics.

Official statistics provide a picture of a country or different phenomena through data, and images such as graph and maps. Statistical System in India: Central and State Government Organizations, Functions of Central Statistical Organization (CSO), National Sample Survey Organization (NSSO). System of Collection of Agricultural Statistics - Crop forecasting

and estimation Productivity, fragmentation of holdings - Support prices - Buffer stocks - Impact of irrigation projects**.** Statistics related to industries, foreign trade - Balance of payment - Inflation - Social statistics. National Income – Measures of national income - Income, expenditure and production approaches - Applications in various sectors in India. Measurement of income inequality: Gini's coefficient, Lorenz curves, Application of Pareto and Lognormal as income distribution.

Suggested readings:

1. Bhaduri, A. (1990). *Macroeconomics:The Dynamicsof Commodity Production*, Macmillan India Limited, New Delhi.
2. Branson, W. H. (1992). *Macroeconomic Theory and Policy*.(3rd ed.). Harper Collins Publishers India (P) Ltd., New Delhi.
3. C. S. O. (1990). *Basic Statistics Relating to the Indian Economy*.
4. C.S.O. (1995). *Statistical System in India.*
5. C. S. O. (1999). *Guide to Official Statistics.*
6. Panse, V. G. (1964). *Estimation of Crop Yields (FAO)*. Food and Agriculture Organization of the United Nations.
7. Central Statistical Organization:http://www.mospi.gov.in/central-statistics-office-cso-0
8. National Sample Survey Office (NSSO) http://www.mospi.gov.in/national-sample-survey-office-nsso
9. Agriculture Survey Reports: https://eands.dacnet.nic.in/