DEPARTMENT OF MATHEMATICS

Course Book for

Mathematics courses
(1) M.Sc. in Mathematics
(2) M.Tech.
(3) Ph.D.

For

Academic Year
2023 - 2024

Visvesvaraya National Institute of Technology,

Nagpur-440 010 (M.S.)

Institute Vision Statement

To contribute effectively to the National and International endeavor of producing quality human resource of world class standard by developing a sustainable technical education system to meet the changing technological needs of the Country and the World incorporating relevant social concerns and to build an environment to create and propagate innovative technologies for the economic development of the Nation.

Institute Mission Statement

The mission of VNIT is to achieve high standards of excellence in generating and propagating knowledge in engineering and allied disciplines. VNIT is committed to providing an education that combines rigorous academics with joy of discovery. The Institute encourages its community to engage in a dialogue with society to be able to effectively contribute for the betterment of humankind.

Department Vision Statement

- To be a leading Mathematics Department in the country.
- To emerge as a global center of learning, academic excellence, and innovative research.

Department Mission Statement

- Imparting of quality mathematics education and the inculcating of the spirit of research through innovative teaching and research methodologies.
- To achieve high standards of excellence in generating and propagating knowledge in Mathematics. Department is committed to providing an education that combines rigorous academics with joy of discovery.
- To provide an environment where students can learn, become competent users of mathematics, and understand the use of mathematics in other disciplines.

Brief about Department of Mathematics :

The Department of Mathematics VNIT Nagpur grew from its humble beginnings in the year 1960. The Department offers several courses in Mathematics to undergraduate and postgraduate students of various science and engineering disciplines. The Department commenced a two-year Master of Science (M.Sc.) program in Mathematics in 2012. Currently, the department has eleven full-time regular highly qualified, enthusiastic and energetic faculty members. All faculty members of the Department hold a PhD degree in Mathematics, with some of them having postdoctoral experience, from reputed institutes in India or abroad.

List of faculty Members

Sr.No.	Faculty Name	Areas of specialization
1.	Dr. G. P. Singh	Relativity and Cosmology,Mathematical Modelling
2.	Dr. P. P. Chakravarthy	Numerical Analysis, Numerical Treatment of Singular Perturbation problems and Singularly Perturbed Differential-Difference equations
3.	Dr. Pallavi Mahale	Functional Analysis andOperator equations
4.	Dr. M.Devakar	Fluid Dynamics
5.	Dr. G. Naga Raju	Numerical Techniques for Partial Differential Equations; Spectral/Finite Element Techniques, Finite Volume Method, Parallel Computing
6.	Dr.Pradip Roul	Numerical analysis of singular BVP, Numerical methods for fractional ODE/PDE, Nuclear Reactor dynamics
7.	Dr. Deepesh Kumar Patel	Nonlinear Analysis, Fixed Point Theory
8.	Dr. Jyoti Singh	Commutative Algebra
9.	Dr. Sourav Pradhan	Queueing Theory; Stochastic Modeling
10.	Dr. Vishnu Pratap Singh	Operation research, Optimization under uncertainty
11.	Dr. Vijender Nallapu	Fractal Approximation
12.	Dr. Purnima Satapathy	Lie Groups and Lie Algebra, Partial Differential Equations
13.	Dr. Sourav Bhattacharya	Planar Topology, Dynamical Systems and Ergodic Theory
14.	Dr. Mohan Kumar Mallick	Nonlinear Elliptic PDEs
16.	Dr. NeelimaBhengra	Wave propagation Theory; Theoretical Seismology; Solid Mechanics

Credit System at VNIT:

Education at the Institute is organized around the semester-based credit system of study. The prominent features of the credit system are a process of continuous evaluation of a student's performance / progress and flexibility to allow a student to progress at an optimum pace suited to his/her ability or convenience, subject to fulfilling minimum requirements for continuation. A student's performance/progress is measured by the number of credits he/she has earned, i.e. completed satisfactorily. Based on the course credits and grades obtained by the student, grade point average is calculated. Aminimum number of credits and a minimum grade point average must be acquired by a student in order to qualify for the degree.

Course credits assignment

Each course, except a few special courses, has certain number of credits assigned to it depending on lecture, tutorial and laboratory contact hours in a week.

For Lectures and Tutorials: One lecture hour per week per semester is assigned one credit and

For Practical/ Laboratory/ Studio: One hour per week per semester is assigned half credit.

Example: Course XXXXXX with (3-0-2) as (L-T-P) structure, i.e. 3 hr Lectures + 0 hr Tutorial + 2 hr Practical per week, will have (3x1 + 0x1 + 2x0.5 =) 4 credits.

Grading System

The grading reflects a student's own proficiency in the course. While relative standing of the student is clearly indicated by his/her grades, the process of awarding grades is based on fitting performance of the class to some statistical distribution. The course coordinator and associated faculty members for a course formulate appropriate procedure to award grades. These grades are reflective of the student's performance vis-à-vis instructor's expectation. If a student is declared pass in a subject, then he/she gets the credits associated with that subject.

Depending on marks scored in a subject, a student is given a Grade. Each grade has got certain grade points as follows:

Grade	Grade points	Description
AA	10	Outstanding
AB	9	Excellent
BB	8	Very good
BC	7	Good
CC	6	Average
CD	5	Below average
DD	4	Marginal (Pass Grade)
FF	0	Poor (Fail) /Unsatisfactory / Absence from end-sem exam
NP	-	Audit pass
NF	-	Audit fail
SS	-	Satisfactory performance in zero credit core course
ZZ	-	Unsatisfactory performance in zero credit core course
W	-	Insufficient attendance

Performance Evaluation

The performance of a student is evaluated in terms of two indices, viz, the Semester Grade Point Average (SGPA) which is the Grade Point Average for a semester and Cumulative Grade Point Average (CGPA) which is the Grade Point Average for all the completed semesters at any point in time. CGPA is rounded up to second decimal.

The Earned Credits (ECR) are defined as the sum of course credits for courses in which students have been awarded grades between AA to DD. Grades obtained in the audit courses are not counted for computation of grade point average.

Earned Grade Points in a semester (EGP) = **Σ** (Course credits x Grade point) for courses in which AA- DD grade has been obtained

SGPA = EGP / Σ (Course credits) for courses registered in a semester in which AA- FF grades are awarded

CGPA= EGP / Σ(Course credits) for courses passed in all completed semesters in which AA- DD grades are awarded

Overall Credits Requirement for Award of Degree

SN	Category of Course	Symbol	Credit Requirement			
			B. Tech. (4-Year)	B. Arch. (5 Year)	M. Tech. (2 Year)	M. Sc. (2 Year)
	Program Core					
1	Basic Sciences (BS)	BS	18	04	-	-
2	Engineering Arts & Sciences (ES)	ES	20	18	-	-
3	Humanities	HU/HM *	05	06	-	-
4	Departmental core	DC	79-82	168	33-39	54-57
Program Elective						
3	Departmental Elective	DE	33-48	17-23	13-19	06-09
4	Humanities & Management	HM	0-6	0-3	-	-
5	Open Course	OC	0-6	0-3	-	-
Total requirement :BS + ES + DC+ DE + HM + OC =			**170**	**219**	**52**	**63**
Minimum Cumulative Grade Point Average required for the award of degree			**4.00**	**4.00**	**6.00**	**4.00**

Attendance Rules

1. All students must attend every class and 100% attendance is expected from the students. However, in consideration of the constraints/ unavoidable circumstances, the attendance can be relaxed by course coordinator only to the extent of not more than 25%. Every student must attend minimum of 75% of the classes actually held for that course.
2. A student with less than 75% attendance in a course during the semester will be awarded W grade. Such a student will not be eligible to appear for the end semester and re-examination of that course. Even if such a student happens to appear for these examinations, then, answer books of such students will not be evaluated.
3. A student with W grade is not eligible to appear for end semester examination, reexamination & summer term.

Scheme for M.Sc. (semester wise):

Semester - I

Sr.No.	Course Code	Course Name	Type	Structure L-T-P	Credits
1	MAL511	Linear Algebra	DC	3-0-0	3
2	MAL512	Real Analysis	DC	3-0-0	3
3	MAL513	Theory of Ordinary Differential Equations	DC	3-0-0	3
4	MAL514	Discrete Mathematics	DC	3-0-0	3
5	CSL501	Introduction to Computer Programming	ES	3-0-0	3
6	HUL505	Communication Skill	HU	Audit course	0
	Elective Credits (DE)= 0, ES Credits=3				
	DC + DE+ES = 15 Credits				

Semester - II

Sr.No.	Course Code	Course Name	Type	Structure L-T-P	Credits
1	MAL521	Complex Analysis	DC	3-0-0	3
2	MAL522	Topology	DC	3-0-0	3
3	MAL523	Algebra	DC	3-0-0	3
4	MAL524	Partial Differential Equation	DC	3-0-0	3
5	MAL525	Numerical Analysis	DC	3-0-0	3
6	MAL526	Numerical Computation laboratory	DC	0-0-2	1
	Elective Credits (DE) = 0				
	DC + DE = 16_ Credits				

Semester - III

Sr.No.	Course Code	Course Name	Type	Structure L-T-P	Credits
1	MAL531	Functional Analysis	DC	3-0-0	3
2	MAL532	Operations Research	DC	3-0-0	3
3	MAL533	Fluid Dynamics	DC	3-0-0	3
4	MAL534	Probability & Statistics	DC	3-0-0	3
5	MAD501	Project Phase I	DC	1-0-0	1
		Core credits(DC)= 13			
		Electives(Any one)			
6.	MAL535	Relativity	DE	3-0-0	3
7.	MAL536	Numerical Solutions of Differential Equations	DE	3-0-0	3
8.	MAL537	Mathematical Modelling	ES	3-0-0	3
9.	MAL 538	Algebraic Topology	DE	3-0-0	3
		Elective credits(DE)= 09, ES Credits=3			

Semester – IV

Sr.No.	Course Code	Course Name	Type	Structure L-T-P	Credits
1	MAL541	Measure Theory and Integration	DC	3-0-0	3
2	MAL542	Integral Transform and Integral Equations	DC	3-0-0	3
3	MAD502	Project Phase II	DC	4-0-0	4
		Core Credits (DC)=10			
		Electives (Any Two)			
4.	MAL543	Operator Theory	DE	3-0-0	3
5.	MAL544	Finite Element Methods	DE	3-0-0	3
6.	MAL545	Numerical methods for Hyperbolic problems	DE	3-0-0	3
7.	MAL546	Bio Mechanics	DE	3-0-0	3
8.	MAL547	Multivariate Data Analysis	DE	3-0-0	3
9.	MAL548	Financial Mathematics	DE	3-0-0	3
10.	MAL550	Numerical Linear Algebra	DE	3-0-0	3
11.	MAL551	Queueing Theory and Stochastic Processes	DE	3-0-0	3
	Elective Credits (DE) = 24				

Course content description:

MAL 511 - Linear Algebra

3 credits (3-0-0)

Objectives: The objective of this subject is to expose student to understand the importance of Linear Algebra to improve ability to think logically, analytically, and abstractly.

Course Outcomes (COs)

After completing this course students will be able to

(1) deal with basic concepts of vector spaces
(2) work out applications related to linear transformation and eigenvalues
(3) understand the follow up courses like numerical analysis, functional analysis

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Vector spaces over fields, Subspaces, Bases and dimension.Matrices, Rank, System of linear equations, Guass elimination.Linear transformations, Representation of linear transformation by matrices, Rank-nullity theorem, Linearfunctional, Annihilator, Double dual, Transpose of a linear transformation.Characteristic values and characteristic vectors of linear transformations, Diagonalizability, Minimal polynomial of a linear transformation, Cayley Hamilton theorem, Invariant subspaces.Direct sum decompositions, Invariant direct sums, The primary decomposition and the Rational form, The Jordan form. Inner product spaces, Orthonormal basis, Gram-Schmidt Theorem.

Text books/ Reference Books:

1. K. Hoffman and R. Kunze, Linear Algebra, Pearson Education(India), 2003.
2. M. Artin: Algebra, Prentice Hall of India, 2005.
3. I. N Herstein: Topics in Algebra, 2 nd Edition, John-Wiley, 1999.
4. S. Lang: Linear Algebra, Springer Undergraduate Texts in Mathematics, 1989.
5. S. Kumeresan: Linear Algebra: A Geometric Approach, Prentice Hall of India, 2004.

MAL512 -Real Analysis
3 Credits (3-0-0)
Objective: The main objective of this course is to express the basic concepts of Real Analysis. Further, students will be exposed to continuity, differentiability, integrability of real functions, convergence of sequence, series and functions (uniform & point wise).
Course Outcomes (COs)
After completing this course students will be able to

(1) Know the fundamentals of real number system, real functions and its properties like continuity, uniform continuity, differentiability and mean value theorems.
(2) Understand the fundamentals of metric spaces, limits and continuity in metric spaces, compact sets, perfect sets, connected sets.
(3) Analyze the convergence properties of sequence and series, uniform and point wise convergence, convergence of power series and their properties.
(4) Understand the concepts of equicontinuity, pointwise and uniform boundedness and know the importance of Ascoli's theorem, Weierstrass approximation theorem.
(5) Expose the concepts of Riemann-Stieltje's integral and some of its properties.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Real number system and its structure, Infimum, Supremum, Dedekind cuts. (proofs omitted)
Functions of single real variable, Limits of functions, Continuity of functions, Types of discontinuities.Uniform continuity. Differentiability and Mean Value Theorems. Metric spaces, limits and continuity in metric spaces, Compact sets, Perfect sets, Connected sets.

Review of convergence of sequences and series of numbers. Sequences and Series of functions, Point wise and uniform convergence, term by term differentiation and integration of series of functions.

Power series-convergence and their properties.Equicontinuity, Pointwise and uniform boundedness, Ascoli's theorem, Weierstrass approximation theorem.

Riemann-Stieltje's integral: Definition and existence of the integral, Properties of the integral.
Text Books / Reference Books:

1. W. Rudin, Principles of Mathematical Analysis McGraw Hill Book Co, 1976.
2. R.G. Bartle, The Elements of Real Analysis, 2nd Ed., J .Wiley, NY, London, 1964.
3. R.R.Goldberg, Methods of Real Analysis, Wiley, 1976.
4. Kenneth A. Ross, Elements of Analysis: The Theory of Calculus, Springer Verlag, UTM, 1980.
5. S. R. Ghorpade and B. V. Limaye, Introduction to Calculus and Real Analysis, Springer, 2006.

MAL513 - Theory of Ordinary Differential Equations
3 Credits (3-0-0)
Objective: The general purpose of this course is to introduce basis concepts of theory of ordinary differential equations, to give several methods including the series method for solving linear and nonlinear differential equations, to learn about existence and uniqueness of the solution to the nonlinear initial value problems.
Course Outcomes (COs):
Upon successful completion of the course, students will be able to:
(1) Solve linear ODEs, systems of linear ODEs and the problems in a number of applications to scientific and engineering problems
(2) Know the existence and uniqueness properties of ordinary differential equations and Picard's theory for the existence of a unique solution of initial value problems
(3) Obtain fundamental matrix and periodic solution of system of ODEs and apply Gronwall's inequality to ODEs.
(4) Understand the theory of continuation of solutions as well as continuous dependence on initial data and on parameters.
(5) Solve boundary value problems and demonstrate the stability of the systems.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):
First order differential equations, Linear differential equations of higher order, Linear dependenceand Wronskian, Basic theory for linear equations, Method of variation of parameters, Linear equations with variable coefficients.

Systems of differential equations, existence and uniqueness theorems, Fundamental matrix, Non-homogeneous linear systems, Linear systems with constant coefficients and periodic coefficients, Existence and uniqueness of solutions, Gronwall inequality, Successive approximation, Picard's theorem, Nonuniqueness of solutions, Continuous dependence on initial conditions, Existence of solutions in the large.
Boundary Value Problems: Green's function, Sturm-Liouville problem, eigenvalue problems.
Stability of linear and nonlinear systems: Lyapunov stability, Sturm's Comparison theorem
Text Books/ Reference Books:
1.S.G.Deo and V. Raghavendra: Ordinary Differential Equations, Tata McGraw Hill Pub. Co., New Delhi, 1997.
2. E.A.Coddington : Introduction to Ordinary Differential Equations, Prentice Hall of India, 1974.

3. D. A. Sanchez, Ordinary Differential Equations and Stability Theory: An Introduction, Dover Publ. Inc.,New York, 1968.
4. M. Rama Mohana Rao: Ordinary differential equations -Theory and applications. Affiliated East West Press, New Delhi, 1980.
5. G.F. Simmons, Differential equations: Theory, Technique and practice, McGraw Hill.

MAL514 - Discrete Mathematics
3 Credits (3-0-0)
Objective: The objective of this subject is to expose student to understand the importance Discrete Mathematical Structures in science and engineering.
Course Outcomes:
After completing this course students will be able to

1. Apply mathematical logic to solve problems and understand sets, relations, functions and discrete structures
2. Understand the notion of mathematical thinking, mathematical proofs, and algorithmic thinking, and be able to apply them in problem solving
3. Formulate problems and solve recurrence relations. Use effectively algebraic techniques to analyse basic discrete structures and algorithms.
4. Understand some basic properties of graphs and related discrete structures and able to model and solve real world problems using graphs and trees.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Sets and propositions: Combinations of sets, Finite and Infinite sets, Uncountably infinite sets, Principle of inclusion and exclusion, Mathematical induction. Propositions, Fundamentals of logic, First order logic, Ordered sets.

Permutations, Combinations, Numeric functions, Generating functions.

Recurrence relations and recursive algorithms:Recurrence relations, Linear recurrence relations with constant coefficients, Solution by the method of generating functions, Sorting algorithm.

Relations and functions: Properties of binary relations, Equivalence relations and partitions, Partial and total ordering relations, Transitive closure and Warshal's algorithm.

Boolean algebra : Chains, Lattices and algebraic systems, Principle of duality, Basic properties of algebraic systems, Distributive and complemented lattices, Boolean lattices and algebras, Uniqueness of finite Boolean algebras, Boolean expressions and functions.

Graphs and planar graphs : Basic terminology, Multigraphs and weighted graphs, Paths and circuits, Shortest paths in weighted graphs, Eulerian paths and circuits, Hamiltonian paths and circuits. Colorable graphs, Chromatic numbers, Fivecolor theorem and Four color problem.

Trees and cut-sets : trees, rooted trees, Path lengths in rooted trees, Spanning trees and BFS & DFS algorithms, Minimum spanning trees and Prims &Kruskal's algorithms.

Text Books/ Reference Books:

1. C.L.Liu: Elements of Discrete Mathematics, McGraw Hill, 1985.
2. J.P. Tremblay and RManohar : Discrete Mathematical Structures with applications to Computer Science, McGraw Hill Book Co., New Delhi 1975.
3. J. L. Mott, A. Kandel and T. P. Baker : Discrete Mathematics for Computer Scientists,Reston Pub. Co, 1983.
4. K.D. Joshi: Foundations in Discrete Mathematics, New Age International, 1989.

MAL 521 - Complex Analysis
3 Credits (3-0-0)

Objective: The objective of this subject is to expose student to understand the importance of complex variables and its applications to science and engineering.
Course Outcomes (COs)
After completing this course students will be able to

(1) Know the fundamentals of complex number system and its properties, extended complex plane, spherical representation.
(2) Expose the concepts of analytic functions and conformal mapping.
(3) Expose the concepts of complex integration and its properties. Know the importance and the proofs of Cauchy theorem and its various extensions.
(4) Analyze the concepts of singularities, zeros of analytic functions, Identity theorem, Maximum modulus theorem, Schwartz's lemma and the importance of Cauchy's residue theorem.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Algebra of complex numbers; Operations of absolute value and Conjugate; Standard inequalities for absolute value, Extended complex plane, Spherical representation.

The exponential and logarithmic functions, Trigonometric functions of a complex variable. Analytic functions as mappings from C to C. Conformality of map linear fractional transformations and their properties and elementary conformal mappings. Examples.

Complex Integration: Line integrals, rectifiable curves; Cauchy theorem, Index of a closed curves, Cauchy's integral formulae, Cauchy's inequality, Liouville's theorem, Morera's theorem, Taylor series expansion.

Singularities: Laurent series expansions, Removable singularities, Poles and essentialsingularities, zeros of analytic functions, Identity theorem, Maximum modulus theorem, Schwartz's lemma, Cauchy's residue theorem; Evaluation of real integrals using Cauchy's residue theorem.

Text Books:/ Reference books:

1. R.V. Churchill and Brown: Complex variables and applications, McGraw Hill, 1990.
2. Murray Speigel: Complex Variables, Shaum's Outline Series, 1964.
3. Ahlfors: Complex Analysis, McGraw-Hill, New York, 1953.
4. Conway: Functions of One Complex Variable, Second Edition, NAROSA Publ., 2002
5. Ponnusamy and Silverman: Complex variables with applications, Birkhauser, 2006.

MAL 522 - Topology
3 Credits (3-0-0)
Objective: The objective of this subject is to provide the student with the concept and the understanding in topological spaces and compact spaces.
Course Outcomes (COs)
After completing this course students will be able to
(1) Understand terms, definitions and theorems related to topology.
(2) Understand definitions and theorems related to subspace, box and product topology.
(3) Demonstrate knowledge and understanding of metric spaces and metric topology.
(4) Demonstrate knowledge and understanding of concepts of Connectedness, Path connectedness, Compact Spaces, Compactness in metric spaces, Local compactness and separation axioms.
(5) Understand and able to prove Uryshon's metrization theorem, Tietz extension theorem, The Tychonoff Theorem.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Topological spaces, Basis for a topology, Subspace topology, Closed Sets.Limit points, Continuous functions, The Product topology, Metric topology, Quotient topology. Connected Spaces, Connected subspaces of R.

Component and path components, Path connectedness, Compact Spaces, Compactness in metric spaces, Local compactness, One point compactification, The countability and Separation axioms, Uryshon's Lemma, Uryshon'smetrization theorem,Tietz extension theorem, The Tychonoff Theorem.

Text books/ Reference Books:

1. J. R. Munkres: Topology, 2nd edition, Pearson Education India, 2001.
2. K. D. Joshi: Introduction to general Topology, New Age Internations, New Delhi, 2000.

3. G. F. Simmons: Introduction to topology and modern analysis, International student edition, 1963.
4. J. V. Deshpande: Introduction to Topology, Tata McGraw Hill, 1988

MAL 523 - Algebra
3 Credits (3-0-0)
Objective: The objective of this subject is to expose student to understand several important concepts in abstract algebra, including group, ring, field, homomorphism, isomorphism, and quotient structure, and to apply some of these concepts to real world problems.
Course Outcomes:
After completing this course students will be able to

1. Understanding of fundamental concepts including groups, subgroups, normal subgroups, direct product of groups, and factor groups.
2. Analyze and implement the concepts of homomorphism and isomorphism between groups and rings for solving different types of algebraic problems
3. Understand the basic concepts of group actions and their applications.
4. Apply class equation and Sylow's theorems to describe the structure of certain finite groups and to solve different problems.
5. Understand rings, fields and their properties

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):
Binary operation, and its properties, Definition of a group, Examples and basic properties. Subgroups, Coset of a subgroup, Lagrange's theorem.
Cyclic groups, Order of a group, Normal subgroups, Quotient group. Homomorphism, Kernel Image of a homomorphism, Isomorphism theorems.
Permutation groups, Cayley's theorems,Direct product of groups. Group action on a set, Semi-direct product.Sylow' theorems.Structure of finite abelian groups.Applications, Some nontrivial Examples.

Rings: definition, Examples and basic properties. Zero divisors,Integral domains, Fields, Characteristic of a ring, Quotient field of an integraldomain. Subrings, Ideals, Quotient rings, Isomorphism theorems.Ring of polynomlals, Prime, Irreducible elements and their properties, UFD, PID and Euclidean domains. Prime ideal, Maximal ideals, Prime avoidance theorem,Chinese remainder theorem.
Text book/ References Books:

1. S. Lang: Algebra Third edition, Addison Wesley,1999.
2. D.S. Dummitand R. M. Foote: Abstract Algebra, 2nd Ed., John Wiley, 2002.
3. M. Artin, Algebra: Prentice Hall of India, 1994.
4. J.A. Gallian: Contemporary Abstract Algebra, 4th Ed., Narosa, 1999.

5 N. Jacobson: Basic Algebra I, 2nd Ed., Hindustan Publishing Co., 1984, W.H. Freeman, 1985.

MAL 524 - Partial Differential Equations
3 Credits (3-0-0)
Objective: The objective of this subject is to expose student to understand the importance of partial differential equations.
Course Outcomes (COs)
After completion of this course students will be able to
1) Deal with linear and quasilinear first order partial differential equations and solve them using Lagranges' method, decide the integrability of pfaffian differential equations in two and three variables, solve the non-linear first order partial differential equations using Charpit's method/Monge's method
2) Solve the higher order partial differential equations with constant coefficients, decide the reducibility of the partial differential equations, classify the second order partial differential equations and reduce the second order partial differential equations to canonical forms using characteristics, solve the homogeneous linear partial differential equations using Fourier's method
3) Obtain solution of boundary value problems concerning Laplace equation using Fourier's method and Green's functions
4) Deal with the one dimensional wave equation with associated initial and boundary conditions using trigonometric series, understand the vibrating membrane
5) Obtain the solution of the initial boundary value problems concerning the diffusion equation in terms of orthogonal functions (method of separation of variables)

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Formulation, Linear and quasi-linear first order partial differential equations, Paffian equation, Condition for integrability, Lagrange's method for linear equations. First order non-linear equations, method of Charpit - method of characteristics.

Equations of higher order : Method of solution for the case of constant coefficients, Equations of second order reduction to canonical forms, Characteristic curves and the Cauchy problem, Riemann's method for the solution of linear hyperbolic equations, Monge's method for the solution of non-linear second order equations,Method of solution by separation of variables.

Laplace's equations: Elementary solutions, Boundary value problems, Green's functions for Laplace's equation, Solution using orthogonal functions.

Wave equations: One dimensional equation and its solution in trigonometric series, Riemann-Volterra solution, vibrating membrane.
Diffusion equations: Elementary solution, Solution in terms of orthogonal functions.

Text Books/ Reference Books:

1. I.N. Sneddon: Elements of Partial Differential Equations, McGraw Hill, New York, 1957.
2. Ioannis P Stavroulakis, Stepan A Tersian : Partial Differential Equations: An Introduction with MATHEMATICA and MAPLE, World scientific, Singapore, 2004.
3. P. Prasad, Renuka Ravindran: Partial Differential Equations, New Age International, 1985.
4. T. Amaranath: An elementary course in Partial differential eqations, Narosa Pub., New Delhi, 2009.

MAL525 - Numerical Analysis
3 Credits (3-0-0)
Objective: The objective of this subject is to expose student to understand the importance of Numerical methods and the analysis behind it.
Course Outcomes (COs)
After completing this course students will be able to
(1) solve the linear and nonlinear (system) equations
(2) approximate the functions based on interpolation and able to evaluate integrals and differentiation of functions
(3) find eigenvalues and eigenvector
(4) find the solution of ordinary differential equations

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):
Interpolation: Existence, Uniqueness of interpolating polynomial, Error of interpolation, Unequally spaced data; Lagrange's, Newton's divided difference formulae. Equally spaced data: finite difference operators and their properties, Gauss's forward and backward formulae, Inverse interpolation,Hermite interpolation.

Differentiation: Finite difference approximations for first and second order derivatives.
Integration: Newton-cotes closed type methods; Particular cases, Error terms, Newton cotes open type methods, Romberg integration, Gaussian quadrature; Legendre, Chebyshev formulae.

Solution of nonlinear and transcendental equations, Regula-Falsi, Newton-Rapson method, Chebyshev's, method, Muller's method, Birge-Vita method, Solution of system of nonlinear equations.

Approximation:Norms, Least square (using monomials and orthogonal polynomials), Uniform and Chebyshev approximations.

Solution of linear algebraic system of equations: LU Decomposition, Gauss-Seidal methods; solution of tridiagonal system. Ill conditioned equations.

Eigen values and Eigen vectors: Power and Jacobi methods.

Solution of Ordinary differential equations: Initial value problems: Single step methods; Taylor's, Euler's, Runge-Kutta methods, Error analysis; Multi-step methods: Adam-Bashforth, Nystorm's, Adams- Moulton methods, Milne's predictor-corrector methods. System of IVP's and higher orders IVP's.

Text Books/ Reference Books:

1. M.K. Jain, S.R.K. Iyengar and R.K. Jain : Numerical Methods for Engineers and Scientists, New Age International, 2003.
2. C.F. Gerald, P.O. Wheatley: Applied Numerical Analysis, Addison-Wesley, 1994.
3. D. Aitkinson : Numerical Analysis, John Wiley and Sons, 2009.
4. Samuel D. Cante and Carl de Boor: Elementary Numerical Analysis, McGraw Hill, 1980.

MAL526 - Numerical Computation Laboratory
1 Credit (0-0-2)
Objective: The objective of this subject is to expose student to practice the numerical methods on computer.
Course Outcomes (COs)
After completing this course students will be able to write programs
(1) related to concepts clarification of the programing language
(2) for the solution linear (system) equations
(3) for the solution of numerical integration
(4) for the solution of differential equations

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise): Programs Based on Numerical Analysis using FORTRAN/C/C++.

Simple programs dealing with fundamental concepts in Fortran programs using conditional statement, Do loops, Subscripted variables, Function subprograms and subroutines.

Programs for solution of quadratic equation, Solution of algebraic and transcendental equations, Gauss-Seidel method, Inverse of a matrix/Gaussian elimination etc., Numerical integration, Euler's and modified Euler's methods, Runge-Kutta methods, Tridiagonal system by Thomas algorithem.

MAL 531 - Functional Analysis
3 Credits (3-0-0)
Objective: This course is intended to introduce the student to the basic concepts and theorems of functional analysis and its applications.
Course Outcomes (COs)
After completing this course students will be able to
(1) Understand fundamental properties, theorems of normed linear spaces, Banach space and Hilbert space.
(2) Understand definitions, properties and theorems related to Bounded linear operators, Linear functionals and closed operators
(3) Understand concept and theorem related to orthogonal set, orthonormal set and orthogonal basis including Bassel inequality and parseval's Formula, Riesz Fischer theorem
(4) Understand and apply fundamental theorems from the theory of Normed linear space and Banach spaces, including the Hahn-Banach theorem, the open mapping theorem, the closed graph theorem.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise): Normed linear spaces, Banach spaces, Hilbert Spaces and basic properties, Heine Borel theorem, Riesz lemma and best approximation property.

Inner product spaces, Projection Theorem; Orthonormal bases, Bassel inequality and parseval's Formula, Riesz Fischer theorem.

Bounded operators, Space of bounded operators and dual space, Riesz representation theorem, Adjoint of operators on a Hilbert Space; unbounded operators, Convergence of sequence of operators.

Hahn Banach extension theorem, Uniform boundedness principle, Closed graph theorem and open mapping theorem, Applications.

Text books\ Reference Books:

1. M. T. Nair, Functional Analysis, A first course, Prentice Hall of India, 2002.
2. B. V. Limaye, Functional Analysis, Second Edition, New Age International, 1996.
3. E. Kreyzig,Introduation to Functional Analysis with Applications, Wiley, 1989.
4. Bollobas, Linear Analysis, Cambridge university Press (Indian Edition)1999.
5. A .E. Taylor and D. C. Lay, Introduction to Functional analysis, 2nd edition, Wiley, New York, 1980.
6. G. F. Simmons: Introduction to Topology, Introduction to Topology and Modern Analysis, International student edition, 1963.

MAL 532 - Operations Research

3 Credits (3-0-0)

Objective: The objective of this subject is to expose student to understand the importance optimization techniques and the theory behind it.

Course Outcomes (COs)

After Completing this course, students will be able to

1. Formulate Linear programming problem of the real life problem occurring in the field of manufacturing and logistics, production planning, Man power problem etc. They can find the optimal solution of such problems using various methods.
2. Formulate Mathematical model and finding optimal solution of Transportation problem, Assignment Problem, Travelling Salesman Problem.
3. Know about non-linear programming problem and its applications in real life situation, method to solve non-linear programming problem.
4. Understand basic of Queuing system, Birth and Death Process, Single server model and the mathematics behind finding the characteristics of these models.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												

CO4												
CO5												

Content (CO wise):
Linear Programming : Lines and hyperplanes, Convex sets, Convex hull, Formulation of a Linear Programming Problem, Theorems dealing with vertices of feasible regions and optimality, Graphical solution.

Simplex method (including Big M method and two phase method), Dual problem, Duality theory, Dual simplex method, Revised simplex method.

Transportation problem, Existence of solution, Degeneracy, MODI method (including the theory).
Assignment problem, Travelling salesman problem.

Nonlinear programming problem: Constrained NLPP, Lagrange's multipliers method - Convex NLPP, Kuhn-Tucker condition (including the proof), Quadratic programming (Wolfe's and Beale's methods)

Queuing theory: Characteristics of queueing systems, Birth and death process, Steady state solutions, Single server model (finite and infinite capacities), Single server model (with SIRO), Models with state dependent arrival and service rates, Waiting time distributions.

Text Books/ Reference Books:

1. J.C. Pant: Introduction to Optimization: Operations Research, Jain Brothers, 1988.
2. H.A.Taha: Operations Research, An Introduction, PHI, 1987.
3. H.M.Wagner: Principles of Operations Research, Prentice Hall of India, Delhi, 1982.
4. Wayne L. Winston: Operations research: Applications and algorithms, Cengage learning Indian edition, 2003.
5. S.S. Rao: Engineering Optimization: Theory & Practice, New Age International(P) Limited, New Delhi, 1996.

MAL 533 – Fluid Dynamics
[3 Credits (3-0-0)]

Objective: The objective of this subject is to expose students to understand the importance of fluid dynamics in Science and Engineering.

Course Outcomes (COs):
After completion of this course students will be able to
1) Deal with both Lagrangian and Eulerian description of fluid motion, find streamlines and pathlines for the given fluid flow
2) Understand the theory behind the continuity equation, Euler equations of motion and Bernoulli equations

3) Deal with 2-dimensional potential flows and 3-dimensional axisymmetric flows of an incompressible ideal fluid. Deal with the flows concerning line source/sink, line doublet, 3-dimensional source/sink, doublet.
4) Understand the relationship between stress and rate of strain for Newtonian fluid, understand the theory behind the Navier-Stokes equations and solve some simple fluid flow problems concerning the Newtonian fluids.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content:

Kinematics of fluids in motion: Real fluids and ideal fluids, Velocity of a fluid at a point , Stream lines and path lines, Steady and unsteady flows, The velocity potential, The velocity vector, Local and particle rates of change, Equation of continuity, Acceleration of fluid , Conditions at a rigid boundary.

Equations of motion of fluid: Euler's equations of motion, Bernoulli's equation, Some flows involving axial symmetry, Some special two-dimensional flows.

Some three dimensional flows: Introduction, Sources, sinks and doublets, Axisymmetric flows, Stokes' stream function. The Milne-Thomson circle theorem, Theorem of Blasius.

Viscous flows: Stress analysis in fluid motion, Relations between stress and rate of strain, Coefficient of viscosity and laminar flow, Navier-Stokes' equations of motion of viscous fluid, Steady motion between parallel planes and through tube of uniform cross section. Flow between concentric rotating cylinders.

Steady viscous flow in tube having uniform elliptic cross section, Tube having equilateral triangular cross section, Steady flow past a fixed sphere.

Text Books:

1. F. Chorlton, Text book of Dynamics, CBS Publishers and Distributors, Delhi, 1998.
2. Whitaker, Introduction to Fluid Mechanics, Prentice-Hall, 1968.

Reference books:

1. N. Curle and H. J. Davies : Modern Fluid Dynamics,Vol. I, 1968.

2. P.K. Kundu and I.M. Cohen, Fluid Mechanics (3rd edition) Elsevier Science & Technology, 2002.
3. L.M.Milne Thomson : Theoretical Hydrodynamics, Macmillan Company, New York, 1955.
4. G.K. Batchelor, Introduction to Fluid Dynamics, Cambridge University Press, 1967.

MAD 501 - Project Phase-I
1 Credit

Objective: The objective of the project is to expose student to understand the importance research in mathematics.

Topic will be decided by the guide and student.

MAL 534 - Probability& Statistics
3 Credits (3-0-0)
Objective: The objective of this subject is to expose student to understand the importance of probability and statistical methods.
Course Outcomes (COs)
After completing this course students will

(1) Understand the significance of probability and statistics in real life, engineering and industrial applications.
(2) Be able to grab the theoretical foundations of conditional probability, random variables, jointdistributions, transformations.
(3) Learn some significant special discrete and continuous distributions.
(4) Be able to use sampling theory, estimation, decision making and regression.
(5) Formulate probabilistic and statistical models of real life/ engineering problems and use them.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Axiomatic definition, properties conditional probability, Independent events, Baey's theorem, Density function, Distribution function, Expectation, Moments, Moment generating function, Characteristic function, Chebyshev inequality, Law of large numbers.

Special distributions: Binomial, Negative Binomial, Geometric, Poisson, Uniform, Normal, Gamma, Exponential, Joint distributions, Marginal and conditional density functions.

Sampling theory for small and large samples, Sampling distributions, Estimation theory and interval estimation for population parameters using normal, t, F and Chi square distributions. Testing of hypothesis and test of significance.

Text Books/ Reference books:

1. V.K. Rohatgi and A.K.M. Ehsanes Sateh : An Introduction to Probability and Statistics, John Wiley & Sons, 2004.
2. J.J. Miller and Freund: Probability and Statistics for Engineering, Person education, 2005.
3. K.S. Trivedi, Probability Statistics with Reliability, Queuing and Computer Science applications, Prentice Hall of India, 1982.
4. M.R. Spiegel, Theory and problems of Probability and statistics, McGraw-Hill Book, 2000.

MAL 535 - Relativity (Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of Relativity.
Course Outcomes (COs)

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Contents (CO wise)
Introduction of Tensors and Tensor calculus, Covariant differentiation, Parallel transport, Riemann curvature tensor, Geodesics.
Principles of special relativity, Line interval, Proper time, Lorentz transformation, Minkowskispacetime, Lightcones, Relativistic momentum 4-vectors, Lorentz transformation of electromagnetic field.
Principle of equivalence, Connection between gravity and geometry, Metric tensor and its properties, Concept of curved spaces and spacetimes, Tangent space and four vectors, Particle trajectories in gravitational field.Einstein's field equations, Definition of the stress tensor, Bianchi identities and conservation of the stress tensor, Einstein's equations for weak gravitational fields, The Newtonian limit.
Derivation of Schwarz'schild metric, Basic properties of Schwarzschild metric coordinate-systems, Effective potential for particle orbits in Schwarzschild metric, general properties Precession of perihelion, Deflection of ultra relativistic particles, Gravitational red-shift.
Models of the universe, Friedmann-Robertson-Walker models, Hubble's law, Angular size. Source counts, Cosmological constant, Horizons. The early universe, Thermodynamics of the early universe.
Microwave background.Observational constraints, Measurement of Hubble's constant, Anisotropy of large-scale Age of the universe, Dark matter.

Text Books:

1. J. V. Narlikar : An Introduction to Relativity, Cambridge University Press (Indian edition by Macmillan company of India Ltd.) 2010.

Reference Books:

2. Ray d'Inverno : Introducing Einstein's Relativity, Clarendon Press, 1996

3. J.V. Narlikar: An Introduction to Cosmology, Cambridge University Press, 2002

4. James B. Hartle: Gravity : An Introduction to Einstein's General Relativity, Pearson Education, 2003

MAL 536 - Numerical Solution of Differential Equations (Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of finite difference methods for solving ordinary and partial differential equations.

Course Outcomes (COs)

After completing this course students will be able to

1. Solve the boundary value problems in ordinary differential equations (both linear and non-linear problems)
2. Understand different types of methods for solving Parabolic, Hyperbolic and Elliptic Partial differential equations.
3. Will be familiar with concepts like consistency, stability and convergence analysis of various numerical schemes.
4. Will be able to develop the programs (using MATLAB or any suitable language) for solving boundary value problems in ODEs as well as PDEs.

Mapping with POs (Departmental reference) *:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Ordinary Differential Equations: Multistep (Explicit and Implicit) Methods for Initial Value problems, Stability and convergence analysis, Linear and nonlinear boundary value problems, Quasilinearization. Shooting methods.

Finite Difference Methods : Finite difference approximations for derivatives, boundary value problems with explicit boundary conditions, Implicit boundary conditions, Error analysis, Stability analysis, Convergence analysis.

Cubic splines and their application for solving two point boundary value problems.

Partial Differential Equations: Finite difference approximations for partial derivatives and finite difference schemes for Parabolic equations : Schmidt's two level, Multilevel explicit methods, Crank-Nicolson's two level, Multilevel implicit methods, Dirichlet's problem, Neumann problem, Mixed boundary value problem. Hyperbolic Equations : Explicit methods, implicit methods, One space dimension, two space dimensions, ADI methods. Elliptic equations : Laplace equation, Poisson equation, iterative schemes, Dirichlet's problem, Neumann problem, mixed boundary value problem, ADI methods.

Text Books:

1. M.K.Jain: Numerical Solution of Differential Equations, Wiley Eastern, Delhi, 1983.
2. G.D.Smith: Numerical Solution of Partial Differential Equations, Oxford University Press, 1985.

Reference Books:

1. P.Henrici : Discrete variable methods in Ordinary Differential Equations, John Wiley, 1964.
2. A.R. Mitchell: Computational Methods in Partial Differential equations, John Wiley & Sons, New York, 1996.
3. Steven C Chapra, Raymond P Canale: Numerical Methods for Engineers, Tata McGraw Hill, New Delhi, 2007.

MAL537 - Mathematical Modeling (Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of Mathematical modelling.
Course Outcomes (COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Need Techniques, Classification and Simple Illustrations. Mathematical modeling through ordinary differential equations and partial differential equations.

Mathematical Modeling Through Graphs. Mathematical modeling through functional integral delay, Differential and differential-difference equations, Mathematical modeling through calculus of variations and dynamic programming, Mathematical modeling through mathematical programming, maximum principle and minimum entropy principle.

Multivariable optimization models, Computational methods for optimization models, Introduction to probability models, Stochastic models.

Text Books/ Reference Books:

1. J.N. Kapur : Mathematical Modeling , New Age International Pub, 1988.
2. Mark M. Meerschaert: Mathematical Modeling, Elsevier Publ., 2007.
3. Edward A. Bender: An introduction to mathematical Modeling, CRC Press,2002
4. Walter J. Meyer, Concepts of Mathematical Modeling, Dover Publ., 2000.

MAL 538- Algebraic Topology
[(3-0-0); Credit: 3]

Pre-requisite: Algebra(MAL523) & Topology(MAL522)

Scope and Objective of the Course: This course enables students to understand topological spaces and continuous maps between them. Algebraic topology provides mathematical understanding in dealing with problems involving shape and position of objects and continuous mappings through algebraic, combinatorial and geometric techniques. This course enables student to study topological spaces through algebraic invariant like homology groups and fundamental group. They should learn the computation of these invariant for topological spaces that will sharpen their geometric intuition. This course will help to solve the problems in topology by reducing it to problems in algebra by means of algebraic invariants. This will help the student to identify the connectivity of different field of mathematics like including geometry, analysis, group theory as well as other sciences like physics and computer science and develop a sense of application of abstract theories.

Course Outcomes (COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Contents :

Fundamental Group: Review of point set topology, Homotopic maps, Homotopy types Contractible spaces, Construction of fundamental group Properties of fundamental groups Fundamental group of circle, Product of spaces and fundamental group of Torus, Spheres, Real projective spaces, Van-Kampen Theorem, Fundamental group of Klein Bottle, Fundamental group of wedge of circles, Definition and Properties,

Covering Spaces : Path Lifting and Homotopy Lifting & applications, Covering Homomorphism, Properties and Group of Deck Transformation, Universal covering spaces,

Simplicial Complexes: Simplicial complexes, Polyhedra and Triangulation, Simplicial approximation and Barycentric subdivision, Orientation of simplicial complexes

Computation of Homology: Chain complex and Homology, Computation of Homology groups of Disc, Spheres, Torus, Projective Plane, Klein bottle etc., Properties of Simplicial Homology, Homomorphisms between Homology groups, Invariance of Homology groups (Lefschetz fixed point Theorem & Borsuk-Ulam Theorem)

Textbooks:

1.Deo, Satya, “Algebraic Topology-A Primer” 2nd Edition, Hindustan Book Agency, 2006

Reference books

1. Hatcher, Allen, “Algebraic Topology” Cambridge University Press. 2002
2. Fulton, William “Algebraic Topology-A first course” Springer-Verlag, 1995
3. Magnus, Karrass and Solitar, “Combinatorial Group Theory: Presentations of Groups in Terms of Generators and Relations” Dover Books on Mathematics, 1976.

MAL 541 - Measure Theory and Integration
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of measure theory and Integration.

Course Outcomes (COs)

The course learning outcomes include the following:

(1) The students will be able to understand the importance of extending the concept of length function from interval to any abstract set and know about the measurable sets.
(2) The student will be able to distingue between measurable sets and non-measurable sets, likewise measurable functions.
(3) The student will be able to use a more general theory of integration in an abstract space which will help in solving various physical well as research problems.
(4) The students will be able to understand the measurability as a condition which is stable under limits, is therefore a natural framework to study properties of integration under limits.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Review of Riemann-Stieltje’s integral: Algebras of sets - Borel subsets of R -Lebesgue outer measure and its properties, Algebras of measurable sets in R - nonmeasurable set, Example of measurable set which is not a Borel set - Lebesgue measure and its properties, Measurable functions, Point wise convergence and convergence in measure,Egoroff theorem.

Lebesgue integral, Lebesgue criterion of Riemann integrability, Fatou’s lemma, Convergence theorem, Differentiation of an integral, Absolute continuity with respect to Lebesgue measure. Lebesgue integral in the plane, Fubini’s theorem.

Text Books:

1. H.L.Royden, Real Analysis, Macmillan, 1968.
2.de Barra, Measure Theory and Integration, Wiley Eastern Ltd., 1981.

Reference Books:

1. I.K. Rana: An Introduction to Measure and Integration, Second Edition,Narosa, 2005.
2. D.L. Cohn: Measure Theory , Birkhauser, 1997.
3. P.K. Jain and V.P. Gupta: Lebesgue Measure and Integration, New Age International, 2006.

MAL 542 - Integral Transforms & Integral Equations
3 Credits (3-0-0)

Objective: The objective of this subject is to expose student to understand the importance of transform techniques like Laplace transforms, Fourier Transforms, Z transforms and Integral equations.

Course Outcomes (COs):
Upon completion of this course, the students will be able to:

(1) Analyze the sufficient conditions for existence of the Laplace transform of the given function. Find the Laplace transform of the elementary functions and apply the Laplace transform for solving the differential equations.
(2) Analyze the relation between the Fourier transform and the Fourier series. Find the Fourier transform of the elementary functions and apply the Fourier transform for solving the partial differential equations.
(3) Covert the linear differential equations to the corresponding Volterra integral equations and vice-versa, and hence analyze the uniqueness of solution of Volterra integral equations. Solve the different types of Volterra integral equations.
(4) Solve the different types of Fredholm integral equations. Analyze the role of the kernel in solving the Fredholm integral equations.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):
Integral Transforms: Laplace transforms: Definitions, Properties, Laplace transforms of some elementary functions, Convolution Theorem, Inverse Laplace transformation, Applications.

Fourier transforms:Definitions,Properties, Fourier transforms of some elementary functions, Convolution theorems, Fourier transform as a limit of Fourier Series, Applications to PDE.

Integral Equations: Volterra Integral Equations: Basic concepts, Relationship between linear differential equations and Volterra integral equations,Resolvent Kernel of Volterra Integral equation, Solution of integral equations by Resolvent Kernel, Method of successive approximations, Convolution type equations, Solution of integral differential equations with the aid of Laplace transformation.

Fredholm Integral equations: Fredholm equations of the second kind, Fundamentals - Iterated Kernels, Constructing the resolvent Kernel with the aid of iterated Kernels, Integral equations with degenerate kernels, Characteristic numbers and eigenfunctions, Solution of homogeneous integral equations with degenerate kernel, Nonhomogeneous symmetric equations,Fredholm alternative.

Text Books/ Reference Books:

1. I.Sneddon, The Use of Integral Transforms (Tata McGraw Hill), 1974.
2. Hildebrand, Methods of Applied Mathematics, Dover Publications; 2nd edition, 1992.
3. SKrasnov, Problems and Exercises in Integral Equations (Mir Publ.), 1971.
4. Ram P Kanwal, Linear Integral Equations (Academic Press), 1971.
5. F.G.Tricomi, Integral Equations, Dover Publications, (1985).
6. J.L. Schiff, The Laplace Transform, Springer (1999)
7. M.R. Spiegel, Laplace Transforms (Schaum's Series), McGraw-Hill, 1965.

MAD 502 - Project Phase –II

4 Credits (4-0-0)

Objective: The objective of the project is to expose student to understand the importance research in mathematics.

MAL 543 - Operator theory (Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of Operator theory.

Course Outcomes(COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Dual space considerations: Representation of duals of the spaces c_{00} c_{00} with p-norms, c_0 c_0 and c with supremum-norm, l_p l_p C[a,b] and L_p L_p. Reflexivity, Weak and weak* convergences. Best Approximation in Reflexive spaces.

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

Spectral results for Banach and Hilbert space operators: Eigen spectrum, Approximate eigen spectrum, Spectrum and resolvent; Spectral radius formula; Spectral mapping theorem;

Riesz-Schauder theory, Spectral results for normal, Self-adjoint and unitary operators; Functions of self-adjoint operators.

Spectral representation of operators: Spectral theorem and singular value representation for compact self-adjoint operators; Spectral theorem for self-adjoint operators.

Text book:

1. M. T. Nair: Functional Analysis: A first course, Prentice Hall of India, 2002.
2. B. V. Limaye: Functional Analysis, Second Edition, New Age Internationals, 1996.

References:

1. E. Kreyzig: Introduation to Functional Analysis with Applications, Wiley, 1989.
2. Bollobas: Linear Analysis, Cambridge university Press, 1999.

MAL544 - Finite Element Method (Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of finite element method.

Course Outcomes (COs):

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Contents:

Calculus of Variations: Variational methods.

Introduction and motivation, Weak formulation of BVP and Galerkin approximation, Piecewise polynomial spaces and finite element method. Results from Sobolev spaces, Variational formulation of elliptic BVP, Lax-Milgram theorem, Estimation for general FE approximation, Construction of FE spaces, Polynomial approximation theory in Sobolev spaces, Variational problem for second order elliptic operators and approximations, Mixed methods, Iterative techniques.

Computer implementation of FEM: Basic of finite element approximation; Mesh generation; Global problem issue; systems of linear equations; Sparse systems.

Text Books:

1. Barna Szabo and Ivo Babuska: Finite Element Analysis, John Wiley And Sons, Inc..
2. D. Braess, Finite elements, Cambridge university press, 1997.
3. J.N.Reddy : An introduction to the Finite Element Method, McGraw Hill.

Reference Books:

S. C. Brenner and L. R. Scott, The Mathematical Theory of Finite Element Methods, Springer.

MAL545 - Numerical Methods for Hyperbolic Problems (Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of Computational fluid dynamics.

Course Outcomes (COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Linear hyperbolic equations: Finite differences, Theoretical concepts of stability and consistency, Order of accuracy, Upwind, Lax Fredrichs and Lax-Wendroff schemes.
Nonlinear equations:One dimensional scalar conservation laws, Review of basic theory, Solutions of the Reimann problem and entropy conditions. First order schemes like Lax Fredrichs, Godunov, Enquist-Osher and Roe's scheme. Convergence results, Entropy consistency and numerical viscosity.
Introduction to the higher order schemes: Lax-Wendroff scheme, Upwind schemes of Van Leer, ENO schemes, Central schemes, Relaxation methods. Introduction to the finite volume methods.

Text Books/ Reference Books:

1. E. F. Toro: Reimann Solvers and Numerical Methods for Fluid Dynamics, Springer, 1999.
2. R. J. LeVeque: Numerical Methods for Conservation Laws, BirkhauserVerlag, 1992.
3. C. B. Laney: Computational Gas Dynamics. Cambridge university press, 1998.
4. Randall J. LeVeque: Finite Volume Methods for Hyperbolic Problems, Cambridge Texts in Applied Mathematics, 2002.

MAL546 - Bio Mechanics (Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of Bio mechanics.
Course Outcomes(COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Fundamental concepts of Biomechanics. Cardiovascular system: Basic concepts about blood, blood vessels, governing equations, models on blood flow, flow in large blood vessels, microcirculation, pulsatile flow, stenotic region flow.

Peristalsis: Basic concepts, governing equations, peristaltic transport under long wave length approximation, peristaltic flow for small amplitudes and small Reynold's number.

Flow in Renal tubules: Basic concepts, governing equations, ultra filteration, flow through proximal tubules, flow through tubes with varying cross section.

Text Book/ Reference Books:

1. Y.C.Fung, Biomechanics, Springer-Verla, Springer; 2nd edition , 1996.
2. J.N.Kapur, Mathematical Models in Biology and Medicine, Affiliated East West Press, New Delhi, 1985.
3. C.G.Caro, T.J.Pedley, R.Schroter : Mechanics of circulation, Oxford University Press., 1978.
4. Susan J Hall,.Basic Biomechanics. Boston: McGraw-Hill Companies, Inc., 1999.

MAL547 - Multivariate Data Analysis (Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of multivariate analysis.

Course Outcomes(COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise): Introduction: The Organization of Data, Distance Matrix Algebra and Random vectors, Mean vectors and Covariance matrices, Matrix Inequalities and Maximization.

Sample Geometry and Random Sampling, Geometry of the sample, Expected values of the sample mean and Covariance matrix, Generalized variance, Sample mean, Covariance and correlation as Matrix operations. Multivariate Normal distribution, Sampling from a multivariate Normal Distribution, Maximum Likelihood Estimation, The sampling distribution of $\bar{\mathbf{X}}$ and S.

Inferences about a Mean Vector, Plausibility of μ_0 as a value for a Normal population Mean, Hotelling's $\mathbf{T^2}$ and Likelihood Ratio Tests Paired Comparisons and a Repeated Measures Design, Comparing Mean Vectors from two populations Introduction to One Way MANOVA.

Multivariate linear Regression Models, Least Squares Estimation, Inferences about the Regression Model, Multivariate Multiple Regression.

Principal Components, Population Principal Components, Graphing the Principal Components.
The Orthogonal Factor Model, Factor rotation, Factor scores, Perspectives and a strategy for factor analysis.

Text Books/ Reference Books:

1. Richard A. Johnson, Applied Multivariate Statistical analysis, Prentice Hall, 2001.
2. Dean W. Wichern, PHI, 3rd Edition – 1996
3. Cooly WW and PR Lohnes – Multivariate Data Analysis-John Wiley & Sons, 1971.
4. J E Hair, W C Black, B. J. Babin, R E Anderson, Multivariate Data Analysis, Prentice Hall, 2009.

MAL548–Financial Mathematics
[(3-0-0); Credit: 3]

Objective:
The main objective of this course is to introduce the financial mathematics and is applications to marketing.
Course Outcomes(COs)
After completing this course, students will be able to
1. Grasp basic terminologies of financial mathematics like, Financial assets, securities, bonds, risk Stocks, Short selling, Portfolio, Options, Forward, Put and Call etc. and its use in Finance.
2. Understand the Mathematics of basic theory of option Pricing, Single and Multi-period binomial pricing model, Binomial Lattice model, Black-Scholes formula and its application in predicting the price of the European and American call and put option.
3. Know about risk and return of an asset, Capital asset pricing model, Theoretical and computational Issues of Markowitz model of portfolio Optimization.
4. Understand the concept of Stochastic Processes, Stochastic Calculus, Filtration and Martingales and its application in predicting the price of the European and American call and put option.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):
Some Basic definitions and terminology.
Basic Theory of Option Pricing: Single and Multi-Period Binomial Pricing Models, Cox-Ross-Rubinstein (CRR) Model, Black-Scholes Formula for Option Pricing as a Limit of CRR Model.

Brownian and Geometric Brownian Motion, Theory of Martingales. Stochastic Calculus, Stochastic Differential Equations, Ito’s Formula to Solve SDE’s. Applications of Stochastic Calculus in Option Pricing.

Mean-Variance Portfolio Theory: Markowitz Model of Portfolio Optimization and Capital Asset Pricing Model (CAPM). Limitations of Markowitz Model and New Measures of Risk.

Interest Rates and Interest Rate Derivatives: Binomial Lattice Model, Vasicek, Hull and White Models for Bond Pricing.

Text books/ Reference Books:

1. D. G. Luenberger: Investment Science, Oxford University Press.
2. M. Capińsky and T. Zastawniak: Mathematics for Finance: An Introduction to Financial Engineering, Springer.
3. Thomas Mikosch: Elementary Stochastic Calculus with Finance in view, World Scientific.
4. Suresh Chandra, S. Dharmaraja, Aparna Mehra, R. Khemchandani: Financial Mathematics: An Introduction, Narosa Publishing House.
5. S. E. Shreve: Stochastic Calculus for Finance, Vol. I & Vol. II, Springer.
6. Sean Dineen: Probability Theory in Finance: A Mathematical Guide to the Black-Scholes Formula, American Mathematical Society, Indian edition.

MAL 550 – Numerical Linear Algebra(Elective)
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the basic importance of Linear Algebra and numerical linear algebra and its applications to science and engineering.

Course Outcomes (Cos)

After completing this course students will be able to

1. Understand various types of errors involved in numerical computation
2. Able to understand various efficient algorithms for solving linear systems of equations and matrix Eigen value problems.
3. Will be familiar with Conditioning, Pivoting
4. Understand the importance of SVD and QR factorization etc.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Special Matrices, Vector and Matrix Norms, SVD. Floating Point Numbers and Errors. Stability, Conditioning and Accuracy. Gauss Elimination and Linear Systems, LU Factorization using Gaussian Elimination, Stability of Gaussian Elimination, Basic Results on Existence and Uniqueness, Some Applications Giving Rise to Linear Systems of Problems, LU Factorization Methods, Conditioning and Pivoting, Inverses and Determinants. Iterative Methods for Large and Sparse Problems: Gauss Seidal, SOR, Chebyshev Acceleration, Conjugate Gradient Method, Preconditioning. QR Factorization, SVD, and Least Squares Solutions. Numerical Eigenvalue Problems, Generalized Eigenvalue Problem.

Text Books/ Reference books:

1. G. H. Golub and C. F. van Loan: Matrix Computations, Johns Hopkins University Press, 1984.

2. L. N. Trefethen and D. Bau, III: Numerical Linear Algebra, SIAM, 1997.

3. G. Allaire and S. M. Kaber: Numerical Linear Algebra, Springer, 2007.

4. B. N. Datta: Numerical Linear Algebra and Applications, Springer, 2008.

MAL 551 – Queueing Theory and Stochastic Processes (Elective)
[(3-0-0); Credit: 3]
Objective: The objective of this subject is to expose student to understand the basic importance of Stochastic Processes and using them to analyze Queueing models withits applications to science and engineering.
Course Outcomes (COs)
After completing this course students will
(1) Be exposed to the fundamentals of queueing models and apply to real life circumstances.
(2) Grab the knowledge of Markov chains, transition probabilities, ergodicity.
(3) Be able to apply those foundations for random walk/ gambler,s ruin/Brownian motion problem.
(4) Be able to use birth-death/Bernoulli/Poisson/renewal processes.
(5) Be able to formulate real life/engineering problems with probabilistic and stochastic arguments.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Introduction to Queueing Systems, Markov Chains and Markov Processes, Poisson, Birth-Death and Markovian Arrival Processes, Simple Queueing Models (M/M/-/- Queues), Queues with Batch Arrivals, M/G/1 and GI/M/1 Queues with Supplementary and Imbedded Markov Chain Approach, Batch Service Queues.

Definition of stochastic processes, Examples and classification, State space and parameter space.

Discrete and Continuous-time Markov Chains (MCs): Transition probability matrix, Chapman-Kolmogorov equations; n-step transition and limiting probabilities, ergodicity, stationary distribution, random walk and gambler's ruin problem, applications of DTMCs. Kolmogorov differential equations for CTMCs, infinitesimal generator, Poisson and birth-death processes, Applications to queueing theory.

Brownian Motion: Wiener process as a limit of random walk; first-passage time and other problems.

Branching Processes: Definition and examples branching processes, probability generating function, mean and variance, Galton-Watson branching process, probability of extinction.

Renewal Processes: Renewal function and its properties, renewal theorems, cost/rewards associated with renewals, Markov renewal and regenerative processes, applications.

Reference Books:

1. Gross, D., Harris, C., 1998. **Fundamentals of Queueing Theory**. Wiley Inter-science, New York
2. Medhi, J., 2002. **Stochastic Models in Queueing Theory**. Academic Press, New York
3. Karlin.S and Taylor**.** H.,1975**. A First course in Stochastic Processes.** Academic Press, New York

Course scheme for M.Tech.

Semester - I

Sr.No.	Course Code	Course Name	Type	Structure L-T-P	Credits
1	MAL401	Finite Difference Methods for differential Equations	DC	3-0-0	3
2	MAL 505	Mathematical elements for Engineers	DC	3-0-0	3
3	MAL 506	Statistical methods for Urban Planning	DC	3-0-0	3
	Core Credits(DC) = 03Credits				

Semester - II

Sr.No.	Course Code	Course Name	Type	Structure L-T-P	Credits
1.	MAL 407	Statistics & Optimization Techniques	DC	3-0-0	3
2.	MAL409	Application of Operational Research Techniques in Construction Management	DE	3-0-0	3
3.	MAL 504	Applied Linear Algebra	DE	3-0-0	3
	Core Credits(DC)= 03 Credits				

Content description for M.Tech

MAL401–Finite Difference methods for Differential equations
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of finite difference methods for solving ordinary and partial differential equations.

Content (CO wise):

After completing this course students will be able to

1. Solve the boundary value problems in ordinary differential equations using finite difference methods
2. Understand different types of methods for solving Parabolic, Hyperbolic and Elliptic Partial differential equations.
3. Will be exposed to understand the methods which are inherent in software packages for solving various engineering problems.
4. Will be exposed to apply these finite difference methods for solving various problems in science and engineering.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Finite difference methods: finite difference approximations for derivatives, boundary value problems with explicit boundary conditions, implicit boundary conditions, Quasilinearization, Cubic splines and their application for solving two point boundary value problems.

Solution of Partial Differential Equations: Classification of partial differential equations, finite difference approximations for partial derivatives and finite difference schemes for:

Parabolic equations: Schmidt's two level, multilevel explicit methods, Crank-Nicolson's method.

Hyperbolic Equations : Explicit methods, implicit methods, one space dimension, two space dimensions.

Elliptic equations: Laplace equation, Poisson equation, iterative schemes.

Computation using MATLAB.

Text Books / Reference Books:

1. G.D. Smith: Numerical solution of Partial Differential equations, Finite Difference methods, Oxford University Press, 1985.
2. M.K. Jain, S.R.K. Iyengar & R.K. Jain: Numerical Methods for Scientific & Engineering Computation, New Age International Publishers, 1996.
3. DR. Lothar Collatz : The numerical treatment of differential equations, Springer-Verlag, New York 1960.
4. K.W. Morton & D.F. Mayers: Numerical solution of Partial differential equations, Cambridge University press. 2005.
5. M.K. Jain : Numerical solution of Differential equations, Wiley Eastern, New Delhi, 1984.

MAL505 - Mathematical Elements for Engineers
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the basic importance of linear algebra and numerical techniques to solve scientific problems and provide advanced knowledge of applied mathematics.

Course Outcomes (COs)

After completing this course students will be able to

(1) Understand the basic importance of linear algebra and numerical techniques to solve scientific problems and improve ability to think logically, analytically and abstractly.
(2) Implement thenumerical techniques to determine the approximate solution ofintegrations.
(3) Solve various initial and boundary value problems in ordinary and partial differential equations arise in the engineering problems by applying the finite difference methods.
(4) Study the changes in the physical world and use the techniques to formulate and solve physical problems mathematically.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Contents:

Linear Algebra & Matrices: Linear Vector Spaces, Linear dependence, basis and dimensions, Four fundamental subspaces, Linear transformations, Transformation from one linear space to another, Inner product space and applications, Eigen values and Eigen vectors, diagonalization, complex matrices, similarity transformations, matrix norms & condition number, iterative methods for solving $AX = b$.

Numerical Techniques: Review of the topics in elementary numerical analysis, Basic Principles, Construction of approximate integration formulae using method of undetermined weights & nodes, Gauss-Legendre formula, Gauss Chebyshev formula, Gauss-Hermite formula, Errors in numerical integration.

Finite Difference Methods: Approximation of derivatives (Ordinary & Partial) in terms of pivotal values: Application to solve

1. Boundary value problems in ordinary differential equations
2. Boundary value problems in partial differential equations: Laplace equation, one-dimensional heat equation and one-dimensional wave equation.

Introduction to Mathematical Modeling: Study of cases of modeling through Linear equations and differential equations.

Text Books:

1. G.D. Smith: Numerical solution of Partial Differential equations, Finite Difference methods, Oxford University Press, 1985.
2. R.K.Jain and S.R.K.Iyengar, Advanced Engineering Mathematics, Narosa Pub. House, 2008.
3. Erwyn Kreyszig, Advanced Engineering Mathematics, John Wiley and Sons, 8^{th} Edition, 2008.
4. M.K.Jain, S.R.K.Iyengar and R.K.Jain, Numerical methods for Scientific and Engineering Computation, New Age International Publications, 2008.

5. G. Strang, Linear algebra and its applications , Thomson Publications (2006).

MAL 506 - Statistical Methods for Urban Planning
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of statistical methods for urban planning.
Course Outcomes (COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Introduction, scope and methods of statistics, frequency distribution, measures of location, dispersion and skewness.
Correlation & regression analysis, least square method – curve fitting
Theory of probability: random variables, some probability distributions – Binomial, Poisson, Normal.
Sampling Theory: Population Parameter, Sample Statistics, Sampling distributions, Sample mean, Sampling distribution of means, the sample variance, the sampling distribution of variance.

Estimation Theory: Point estimate and interval estimates, reliability, confidence interval estimates of population parameters, confidence intervals for means, proportions and variance.

Tests of Hypothesis and Significance: Statistical decisions, tests of hypotheses and significance, Type I and Type II errors, level of significance, one tailed and two tailed tests. Tests involving small samples and large samples, fitting theoretical distributions to sample frequency distribution, The chi-square test for goodness of fit.

Text books/ Reference books:

1. S.C. Gupta and V.K. Kapoor: Fundamentals of Mathematical Statistics, Khanna Publishers, New Delhi, 1989.
2. M.R. Speigel: Probability and Statistics, McGraw-Hill, 1995.
3. Vijay K. Rohatgi & A.K. Md. Ehsanes Saleh: An Introduction to Probability and statistics , John Wiley & Sons Inc., New York, 1976.
4. Kishor S. Trivedi : Probability & Statistics with reliability, Queuing and computer Science applications, PHI private Ltd, 2009.

MAL 407 - Statistics & Optimization Techniques
[(3-0-0); Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of statistical analysis. It also focuses the optimization techniques to solve linear and nonlinear programming problems.
Course Outcomes(COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Statistics -

Sampling Theory : Population Parameter, Sample Statistics, Sampling distributions, Sample mean, Sampling distribution of means, the sample variance, the sampling distribution of variance.

Estimation Theory: Point estimate and interval estimates, reliability, confidence interval estimates of population parameters, confidence intervals for means, proportions and variance.

Tests of Hypothesis and Significance: Statistical decisions, tests of hypotheses and significance, Type I and Type II errors, level of significance, one tailed and two tailed tests. Tests involving small samples and large samples, fitting theoretical distributions to sample frequency distribution, The chi-square test for goodness of fit.
O. R. Techniques-

Linear Programming: Formulation of linear programming problem, Graphical solution- simplex method (including Big M method and two phase method), dual problem- duality theory, dual simplex method, revised simplex method.
Transportation problem: Existence of solution-degeneracy- MODI method; Assignment problem- traveling salesman problem
Nonlinear programming problem (NLPP): Constrained NLPP, Lagrange's multipliers method – convex NLPP, Kuhn-Tucker conditions.

Text Books:

1. M.R. Speigel: Probability and Statistics, McGraw-Hill, 1995.
2. H.A. Taha : Operation Research Prentice Hall of India Pvt. Ltd, 1998.

Reference Books:

1. J.C. Pant, Introduction to Optimization: Operations Research Jain Brothers, New Delhi, 2004.
2. Miller and Freund, Probability and Statistics for Engineers, Economy Edition, PHI, 8th Edition, 2011.

MAL409 - Application of Operational Research Techniques in Construction Management [(3-0-0);Credit: 3]

Objective: The objective of this subject is to expose student to understand the importance of operational research to solve problems related to construction management.

Course Outcomes (COs)

After Completing this course, students will be able to

1 Formulate Linear programming problem of the real life problem occurring in the field of manufacturing and logistics, production planning, Man power problem etc. Formulate Mathematical model and finding optimal solution of Transportation problem, Assignment Problem, Travelling Salesman Problem.

2 Know about Dynamic Programming method and its stage wise solution procedure to solve a problem stage wise.

3 Understand basic of Inventory Management, Sequencing, Game Theory and its real line application in the field of construction management.

4 Deal with Simulation as applied to construction. Modifications and improvements on CPM/PERT techniques applications to construction management.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Introduction to linear programming, transportation and assignment problems. Dynamic programming waiting line models.

Inventory Management, Sequencing, Decision theory, Game theory, Simulation as applied to construction. Modifications and improvements on CPM/PERT techniques applications to construction management.

Text books:

1. N. D. Vohra : Quantitative Techniques in Management , The Mc. Graw Hill Companies.
2. J.C. Pant, Introduction to Optimisation : Operations Research Jain Brothers, New Delhi.
3. H.M.Wagner : Principles of Operations Research, Prentice Hall of India, New Delhi.
4. Kambo : Mathematical Progamming Techniques, East-West Publishers, New Delhi..

MAL 504- Linear Algebra
[(3-0-0); Credit: 3]
Objective:
Course Outcomes (COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise) :

vector spaces, linear independence, bases and dimension, linear maps and matrices, eigenvalues, invariant subspaces, inner products, norms, orthonormal bases, spectral theorem, isometries, Linear Transformations, The Null Space and the Range Space of a Linear Transformation, , The Rank-Nullity-Dimension Theorem. Isomorphisms between Vector Spaces, polar and singular value decomposition, operators on real and complex vector spaces, characteristic polynomial, minimal polynomial.

Text books/ Reference Books:

1. K. Hoffman and R. Kunze, Linear Algebra, Pearson Education (India).
2. M. Artin: Algebra, Prentice Hall of India.
1. I. N Herstein: Topics in Algebra, 2 nd Edition, John-Wiley.
2. S. Lang: Linear Algebra, Springer Undergraduate Texts in Mathematics.
3. S. Kumeresan: Linear Algebra: A Geometric Approach, Prentice Hall of India

Scheme of Instruction for Ph. D. (Mathematics)

Sr.No.	Course Code	Course Name	Type	Structure L-T-P	Credits
1	MAL601	Singular Perturbation Theory	DC	3-0-0	3
2	MAL602	Fitted Numerical Methods for Singular Perturbation Problems	DC	3-0-0	3
3	MAL 603	Non-linear dynamical systems	DC	3-0-0	
4	MAL604	Advanced Fluid Dynamics	DC	3-0-0	3
5	MAL605	Theory of Micro polar and Couple stress fluids	DC	3-0-0	3
6	MAL606	Cosmology	DC	3-0-0	3
7	MAL 607	Fixed point Theory and Application	DC	3-0-0	3
8	MAL 608	High resolution schemes for non-linear PDEs	DC	3-0-0	3
9	MAL 609	Advance Approximation Theory	DC	3-0-0	3
10	MAL 610	Non-linear Approximation Theory	DC	3-0-0	3
11	MAL 611	Matrix Iterative Analysis	DC	3-0-0	3
12	MAL 612	Nonlinear Analysis and Applications	DC	3-0-0	3
13	MAL 613	Introduction to Ill-posed Operator Equations	DC	3-0-0	3
14	MAL 614	Lie Groups and Lie Algebras to Ordinary Differential Equations	DC	3-0-0	3

15	MAL615	Lie symmetry analysis to Partial Differential Equations	DC	3-0-0	3
16	MAL616	Fractal Approximation	DC	3-0-0	3
17	MAL617	Fuzzy Set Theory and its Applications	DC	3-0-0	3

Course content description :

MAL 601 - Singular Perturbation Theory
[3-0-0; Credits 3]
Objective:
Course Outcomes:
After completing this course students will be
1. Familiar with asymptotic expansions, composite expansions
2. Able to understand the analytical methods to handle the problems possessing boundary layers
3. Familiar with multi scale phenomena, WKB theory
4. Also understand various advanced mathematical methods to handle singular perturbation problems.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Mathematical preliminaries:
Little-*oh*, Big-*oh,* Asymptotically equal to or behaves like notations, Asymptotic sequences and asymptotic expansions, Convergent series versus divergent series, Asymptotic expansions with a parameter, Uniformity or breakdown, Intermediate variables and the overlap region, the matching principle, matching with logarithmic terms, composite expansions.

Introductory applications:
Roots of equations, integration of functions represented by asymptotic expansions, ordinary differential equations: regular problems, simple singular problems, scaling of differential equations, equations which exhibit a boundary layer behavior, where is the boundary layer? boundary layers and transition layers.

The method of multiple scales:
Nearly linear oscillations, nonlinear oscillators, applications to classical ordinary differential equations, WKB method for slowly varying oscillations, turning point problem, applications to partial differential equations, limitation on the use of the method of multiple scales, boundary layer problems.
Some physical applications of singular perturbation problems:
Books:

1. R.S. Johnson , Singular perturbation theory : Mathematical and analytical techniques with applications to engineering , Springer, 2005.
2. Ali Hasan Nayfeh, Perturbation methods, John-Wiley & Sons, New-York, 1972.
3. Carl M. Bender, Steven A. Orszag, Advanced mathematical methods for scientists and engineers: Asymptotic methods and perturbation theory, Springer, 2010.
4. O'Malley, R.E.: Introduction to Singular Perturbations, Academic Press, New York, 1974.
5. O'Malley, R.E.: Singular Perturbation Methods for Ordinary Differential Equations, Springer-Verlag, New York, 1991.
6. Smith, D.R.: Singular Perturbation Theory – An Introduction with applications, Cambridge University Press, Cambridge, 1985.
7. Van Dyke, M.: Perturbation Methods in Fluid Mechanics, Academic Press, New York, 1964.
8. Kevorkian, J. and Cole, J.D. : Perturbation Methods in Applied Mathematics, Springer-Verlag, New York, 1981.

MAL 602 - Fitted Numerical Methods for Singular Perturbation Problems
[3-0-0; Credits 3]

Objective: Motivation for the study of singular perturbation problems, simple examples of singular perturbation problems.
Course Outcomes:
After completing this course students will be able to
1. Understand the uniformly convergent numerical schemes for problems with initial layers
2. Understand the uniformly convergent numerical schemes for problems with boundary layers
3. Understand the construction of fitted mesh methods
4. Understand the fitted numerical methods for problems parabolic boundary layers.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												

CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Uniform numerical methods for problems with initial and boundary layers:

Initial value problems- some uniformly convergent difference schemes, constant fitting factors, optimal error estimates. Boundary value problems- constant fitting factors for a self adjoint problem, non self adjoint problem, self adjoint problem in conservation form, non self adjoint problem in conservation form, problems with mixed boundary conditions, fitted versus standard method, experimental determination of order or uniform convergence.

Simple fitted mesh methods in one dimension, convergence of fitted mesh finite difference methods for linear convection-diffusion problems in one dimension, linear convection-diffusion problems in two dimensions and their numerical solutions, fitted numerical methods for problems with initial and parabolic boundary layers.

Books

1. Doolan, E.P., Miller, J.J.H. and Schilders, W.H.A. : Uniform Numerical Methods for problems with Initial and Boundary Layers, Boole Press, Dublin, 1980.
2. Miller, J.J.H., O'Riordan, E. and Shishkin, G.I. : Fitted Numerical methods for singular perturbation problems, World Scientific, River Edge, NJ, 1996.

MAL 603 Nonlinear Dynamical Systems
[3-0-0; Credits 3]

Objective:

Course Outcomes:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise): Continuous dynamical systems, Equilibrium points. Linearization. Hartman-Grobman theorem. Linear stability analysis. Liapunov Theorem and global stability. Stable, unstable and central manifolds: Stable and central manifold theorems. Phase-plane analysis. Constructing phase plane diagrams.

Hamiltonian systems, conservative systems, dissipative systems. Limit cycles: Existence and uniqueness of limit cycle. Poincare-Bendixson theorem.

Bifurcations: Saddle-node, transcritical, pitchfork(supercritical and subcritical), Hopf-Andronov (Supercritical and subcritical), omoclinic, Heteroclinic and Bogdanov-Takens bifurcations (Normal forms and their applications).

Strange attractors and Chaos: Lorentz system, Lienard systems, Henon map, Rossler system and food chain model. Constructing phase bifurcation diagrams. Cascades of periodic doubling bifurcation. Lyapunov exponents.

Books:

1. L. Perko,Differential equations and dynamical systems, volume 7. Springer, 2000.
2. Steven H. Strogatz,Nonlinear Dynamics and Chaos with applications to Physics, Biology, Chemistry and Engineering, Levant Books, 2007.
3. S. Wiggins,Introduction to Applied Nonlinear Dynamical Systems and Chaos, Springer, Volume 2, 2003.
4. M.W. Hirsch, S. Smale, and R.L. Devaney,Differential equations, dynamical systems and an introduction to chaos, volume 60. Academic Press, 2004.
5. Yuri A. Kuznetsov,Elements of applied bifurcation Theory, Springer, 2004.

MAL 604 - Advanced Fluid Dynamics
[(3-0-0); Credit: 3]
Objective: The objective of this subject is to expose students to understand the importance of fluid dynamics in Science and Engineering, and also make them understand & solve diverse fluid flow problems.
Course Outcomes:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise) :

Equations governing the motion of viscous fluid:
Viscosity, Newton law of viscosity; stress and rate of strain tensors; Law of conservation of mass, continuity equations; law of conservation of momentum, Navier-Stokes equations for viscous fluids; law of conservation of angular momentum; law of conservation of energy and energy equation.

Boundary conditions: No slip boundary condition, slip boundary condition.

Some simple viscous fluid flows:
Steady motion between parallel planes and through tube of uniform cross section. Flow between concentric rotating cylinders. Flow of two immiscible fluids (with different viscosities) between parallel plates, flow of two immiscible fluids with different viscosities through a circular tube.

Steady viscous flow in tube having uniform elliptic cross section, Tube having equilateral triangular cross section, Steady flow past a fixed sphere.

Unsteady flows:
Unsteady unidirectional flows above flat plate due to impulsive motion of flat plate; unsteady unidirectional flows between two parallel plates due to impulsive motion of plates; unsteady unidirectional flow through circular cylindrical pipe due the impulsive motion of the pipe, unsteady unidirectional flow through concentric cylinders due to the impulsive motion of the cylinders; unsteady unidirectional flows of two immiscible fluids between parallel plates due to impulsive motion of the plates; unsteady unidirectional flows of two immiscible fluids through cylindrical pipe due to the impulsive motion of the pipe.

Flows with low and high Reynolds number:
Reynolds number (Re), flows with negligible inertia (Re<<1), flows with high Reynolds number (Re>>1).
Books:

1. F. Chorlton, Text book of Dynamics, CBS Publishers and Distributors, Delhi, 1998.
2. I.G.Currie, Fundamental Mechanics of Fluids, Marcel Dekker, Inc.: New York. 2003.
3. W. E. Langlois, M.O.Deville, Slow Viscous Flow (2nd Edition), Springer, 2014.
4. S.Whitaker, Introduction to Fluid Mechanics, Prentice-Hall, 1968.
5. G.K. Batchelor, Introduction to Fluid Dynamics, Cambridge University Press, 1967.

6. D.J.Acheson, Elementary Fluid Dynamics, Oxford University Press
7. H. Schlichting, K. Gersten, Boundary Layer Theory, Springer Science & Business Media, 2000.
8. Y.A.Cengel, J.M.Cimbala, Fluid Mechanics: Fundamentals and Applications, Tata McGraw-Hill Publishing Company Ltd., New Delhi, 2006.

MAL 605 - Theory of Micropolar and Couplestress fluids
[(3-0-0); Credit: 3]

Pre-requisites: Fluid Dynamics
Objective: The objective of this subject is to expose students to understand the dynamics of micropolar and couple stress fluids and also make them to solve some flow problems concerning these fluids.
Course Outcomes:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise) :

Kinematics of Fluids Flow: Introduction, Velocity Gradient Tensor, Rate of Deformation Tensor, Analysis of Strain Rates, Spin Tensor, Curvature-Twist Rate Tensor, Objective Tensors, Balance of Mass.

Governing Equations: Introduction, Measure of Mechanical Interactions, Euler's Laws of Motion, Stress and Couple Stress Vectors, Stress and Couple Stress Tensors, Cauchy's Laws of Motion, Analysis of Stress, Energy Balance Equations, Entropy Inequality

Couple Stress Fluids: Introduction, Constitutive Equations, Equations of Motion, Boundary Conditions, Steady Flow between Parallel Plates, Steady Flow between Two Co-axial Cylinders, Poiseuille Flow through Circular Pipe, steady immiscible flows between parallel plates, steady immiscible flows through cicular cylindrical pipe.

Micro Fluids: Introduction, Description of Micromotion, Kinematics of Deformation, Conservation of Mass, Balance of Momenta, Microinertia Moments, Balance of Energy, Entropy Inequality, Constitutive Equations for Micro Fluids, Linear Theory of Micro Fluids, Equations of Motions.

Micropolar Fluids: Introduction, Skew-symmetric of the Gyration Tensor and Microisotropy, Micropolar Fluids, Thermodynamics of Micropolar Fluids, Equations of Motion, Boundary and Initial Conditions, Two Limiting Cases, Steady Flow between Parallel Plates, Steady Couette Flow between Two Co-axial Cylinders, Pipe Poiseuille Flow, steady immiscible flows between parallel plates, steady immiscible flows through circular cylindrical pipe.

Reference Books:

1. Vijay Kumar Stokes, Theory of Fluids with Microstructure – An Introduction, 1984, SpringerVerlag.
2. R. Aris, Vectors, Tensors, and the Basic Equations of Fluid Mechanics, 1990, Dover Publications Inc.
3. A.C. Eringen, Microcontinuum Field Theories I Foundations and Solids, 1999, Springer.
4. A.C. Eringen, Microcontinuum Field Theories II Fluent Media, 2001, Springer.
5. G. Lukaszewicz, Micropolar Fluids Theory and Applications, 1999, Birkhauser Boston.
6. R.K. Rathy, An Introduction to Fluid Dynamics, 1976, Oxford & IBH Publishing.
7. William F. Hughes, John A. Brighton, Fluid Dynamics, 3rd Ed., 2004, Tata McGraw- Hill.

8. M. Devakar, N. Ch. Ramgopal, Fully Developed Flows of Two Immiscible Couple stress and Newtonian Fluids Through non-Porous and Porous Medium in a Horizontal Cylinder, Journal of Porous Media, 18 (2015), 549-558.
9. M. Devakar, N. Ch. Ramgopal, Unidirectional Flows of Two Immiscible Micropolar and Newtonian Fluids Through non-Porous and Porous Medium in a Horizontal Circular Cylinder, Preprint, 2015.
10. J. C. UMAVATHI, J. PRATHAP KUMAR, Ali J. CHAMKHA, Convective Flow of Two Iimmiscible Viscous and Couplestress Permeable Fluids Through a Vertical Channel, Turkish J. Eng. Env. Sci., 33 (2009) , 221 – 243.
11. J. Prathap Kumar, J.C. Umavathi, Ali J. Chamkha, Ioan Pop, Fully Developed Free Convective .

MAL 606 – Cosmology

[(3-0-0) ; Credits : 3]

Pre-requisite : Relativity (MAL 535)

Objective: The objective of this subject is to expose student to understand the importance of cosmology which deals origin, structure formation and evolution of the universe.

Course Outcomes:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

An overview of the large scale structure of the universe. Einstein's modified field equations with the cosmological term. Static cosmological models of the Einstein and de-Sitler; their derivation, geometrical and physical properties and comparison with the actual universe. Hubble's law, non-static cosmological models, cosmological principles and Weyl's postulate. Derivation of the Robertson-Walker metric and its geometrical properties. Hubble and deceleration parameters. Red shift in the Robertson-Walker geometry. Einstein's equations for the Robertson-Walker metric, fundamental dynamical equations of the standard big-bang cosmology-Friedman Robertson-Walker models. Initial singularity-the big bang, density and pressure in the present universe. Critical density-the open, closed and flat universes. Age of the universe. The radiation and matter dominated era of the universe. The red shift versus distance relation. Event and particle horizons. Observational constraints, Measurement of Hubble's constant, Dark matter and Dark energy.

Recommended Books:

1. R. C. Tolman, Relativity, Thermodynamics and Cosmology, Clarendon Press, Oxford, 1934.
2. S. Weinberg, Gravitation and Cosmology, John Wiley, 1972.
3. J. V. Narlikar, Introduction to Cosmology, Cambridge University Press, 1998.
4. J. N. Islam, An Introduction to Mathematical Cosmology, Cambridge University Press, 1999.
5. J. A. Peacock, Cosmological Physics, Cambridge University Press, 1999.

MAL607 - Fixed Point Theory and Applications
[(3-0-0); Credit: 3]
Pre- requisite: Real Analysis, Functional Analysis, Topology
Course Outcomes
After completion of this course students will be able to

(1) Understand the importance of various properties of the involved operators, the geometry of the Banach space, etc.
(2) Understand the importance of some basic fixed point theorems and their applications.
(3) To understand the various existence criteria of fixed points multivalued mapping and non-expansive mappings.
(4) To have an ability of working on the research problems in the area of fixed point theory.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):
Fundamentals: Topological spaces, Normed spaces, Dense set and separable space, Linear operators, Space of bounded linear operators, Hahn-Banach theorem and applications Compactness, Reflexivity, Weak topologies, Continuity of mappings, Convexity,

Smoothness, Duality Mappings: Strict convexity, Uniform convexity, Convex functions Smoothness, Banach limit, Metric projection and retraction mappings,

Geometric Coefficients of Banach Spaces: Asymptotic centers and asymptotic radius, The Opial and uniform Opial conditions, Normal structure
Existence Theorems in Metric Spaces: Contraction mappings and their generalizations, Multivalued mappings, Convexity structure and fixed points, Normal

structure coefficient and fixed points, Lifschitz's coefficient and fixed points

Existence Theorems in Banach Spaces: Non-self contraction mappings, Nonexpansive mappings, Multivaluednonexpansive mappings, Asymptotically nonexpansive mappings,

Uniformly L-Lipschitzian mappings, Non-Lipschitzian mappings, Pseudocontractive mappings

Approximation of Fixed Points: Basic properties, Convergence of successive iterates, Mann iteration process, Nonexpansive and quasi-nonexpansive mappings

The modified Mann iteration process, The Ishikawa iteration process, The S-iteration process

Strong Convergence Theorems: Convergence of approximants of self-mappings, Convergence of approximants of non-self mappings, Convergence of Halpern iteration process

Applications of Fixed Point Theorems: Attractors of the IFS, Best approximation theory, Solutions of operator equations, Differential and integral equations, Variational inequality, Variational inclusion problem

Books:

1. Ravi P. Agarwal, DonalO'Regan, and D.R. Sahu, Fixed Point Theory for Lipschitzian-type Mappings with Applications, Springer New York 2009.

2. Mohamed A. Khamsi and William A. Kirk, An Introduction to Metric Spaces and Fixed Point Theory, John Wiley &Sons, inc.2001.

MAL 608 High Resolution Schemes for Non-linear Partial Differential Equations(Elective)

[(3-0-0) ; Credits : 3]

Objective:

Course Outcomes(COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Introduction to linear system of hyperbolic conservation laws: Review of first order and second order schemes, REA-algorithm, Godunov, Lax-Friedriches and Rusanov schemes. Upwind schemes: MUSCL Schemes, Finite volume and finite difference ENO schemes, Third, fifth and higher order WENO schemes Central schemes: NT scheme, KT scheme and central WENO schemes. Euler system in 1D and 2D: Some properties, Riemann problem for the Euler equations, Approximate Riemann solvers: HLL, HLLC and Roe solvers. Time discretisation methods: TVD and non-TVD Runge-Kutta schemes, Lax-Wendroff type time discretisation methods.

References:

1. R. J. LeVeque, Finite Volume Methods for Hyperbolic Problems, Cambridge Texts in Applied Mathematics, Cambridge University Press, Cambridge 2002.

2. E. F. Toro, Riemann Solvers and Numerical Methods for Fluid Dynamics, A Practical Introduction. Third Edition, Springer 2009.
3. C.W. Shu, Essentially Non-Oscillatory and Weighted Essentially Non-Oscillatory schemss for Hyperbolic Conservation Laws, NASA/CR-97-206253, ICASE, Report No.97-65,1997.
4. T.J. Barth, H. Deconinck (Eds.), High-Order Methods for Computational Physics, Series: Lecture Notes in Computational Science and Engineering, Vol. 9, Springer 1999.

MAL 609-Advance Approximation Theory

[3-0-0; 3 Credits]

Pre-requisite: Real Analysisand Functional Analysis

Objective: The main objective of this course is to provide the concept of best approximation and various tools in approximation theory.

Course Outcomes(COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Concept of best approximation in a normed linear space, Existence of the best approximation, Uniqueness problem, Convexity: uniform convexity,strict convexity and their relations, Continuity of the best approximation operator.

The Weierstrass theorem, Bernstein polynomials, Korovkin theorem, Algebraic and trigonometric polynomials of the best approximation, Lipschitz class, Modulus of continuity, Integral modulus of continuity and their properties.

Bernstein's inequality, Jackson's theorems and their converse theorems, Approximation by means of Fourier series.

Positive linear operators, Monotone operators, Simultaneous approximation, L-p approximation, Approximation of analytic functions.

Introduction to q-calculus, q-derivative and h-derivative, Generalized Taylor's formula for polynomials, q-Taylor's formula for polynomials, Euler's identities and q-exponential functions, Jackson Integral, Fundamental theorem of q-Calculus, q-Gamma and q-Beta functions and properties of q-Bernstein polynomials.

Text books/ Reference Books:

1. Mhaskar, H. M. and Pai, D. V., "Fundamentals of Approximation Theory", Narosa Publishing House, 2000.
2. Timan, A. F., "Theory of Approximation of Functions of a Real Variable", Dover Publication Inc, 1994.
3. V. Kac, P. Cheung, Quantum Calculus Universitext, Springer, New York, 2002.
4. Cheney, E. W., "Introduction to Approximation Theory", AMS Chelsea Publishing Co, 1981.
5. Lorentz, G. G., "Bernstein Polynomials", Chelsea Publishing Co, 1986.
6. Natanson, I. P., "Constructive Function Theory Volume-I", Fredrick Ungar Publishing Co, 1964.

MAL 610 - Nonlinear Approximation Theory
[3-0-0; 3 Credits]

Pre-requisite: Real Analysisand Functional Analysis

Objective: The main objective of this course is to provide the concept of nonlinear approximation and its applications.

Course Outcomes(COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise):

Functions and Convergence, Fourier Series and The Fourier Transform, Fourier inversion, Convolution, Plancherel's formula, The Fourier transform for L^2 functions, Bandlimited functions and Shannon Sampling theorem.

Kernel functionals, Modular Spaces and modular convergence, Quasiconvex modulars, Subbounded modulars.

Approximation by Sampling series, Lagrange interpolation and Sampling theorems, Kantorovich sampling series by means of Orlicz Spaces, convergence in $L^p(\Re)$ -space, L log L-space and exponential spaces.

Generalized Kantorovich-type sampling series, L^p spaces, Operator norms, Modulus of smoothness, Order of approximation, Singular integral of Fejer's type and its approximation properties.

Approximation by convolution type operators, Embedding theorems, the error of modular approximation, Convergence theorems and Rates of modular approximation in modular Lipschitz classes.

Text books/ Reference Books:

1. C. Bardaro , J. Musielak and G. Vinti, ''Nonlinear Integral Operators and Applications'', Walter de Gruyter , Berlin , Springer, 2003.
2. P. L. Butzer, G. Schmeisser and R.L. Stens, 'Non uniform Sampling, Theory and Practice,''Kluwer Academic/Plenum Publishers, New York, Springer, 2001.
3. P. L. Butzer and R.J. Nessel, Fourier Analysis and Approximation, Birkhauser Verlag, Basel and Academic Press, New York, 1971.
4. J. Musielak, Orlicz Spaces and Modular Spaces, in: Lecture Notes in Mathematics, vol. 1034, Springer-Verlag, Berlin, 1983.
5. D. F. Walnut, An Introduction to Wavelet Analysis, Birkhäuser, Springer, 2004.

MAL 611 - Matrix Iterative Analysis

[(3-0-0); Credit: 3]

Objective: The objective of this course is to introduce students to the basic concepts and analysis of matrix numerical methods which are in iterative nature.

Course Outcomes(COs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Content (CO wise) :

1. Matrix Properties and Concepts:
Norms and Spectral Radii, Bounds for the Spectral Radius of a Matrix and Directed Graphs, Diagonally Dominant Matrices, Ovals of Cassini.

2. Nonnegative Matrices:
Spectral Radii of Nonnegative Matrices, Cyclic and Primitive Matrices, Reducible Matrices, Nonnegative Matrices and Directed Graphs.

3. Basic Iterative Methods and Comparison Theorems:
The Point Jacobi, Gauss-Seidel, and Successive Overrelaxation Iterative Methods, Average Rates of Convergence, The Stein-Rosenberg Theorem, The Ostrowski-Reich Theorem, Stieltjes Matrices, M-Matrices and H-Matrices, Regular and Weak Regular Splittings of Matrices.

4. Successive Overrelaxation Iterative Methods:
P-Cyclic Matrices, The Successive Overrelaxation Iterative Method for p-Cyclic Matrices, Theoretical Determination of an Optimum Relaxation Factor.

Text Books:

1. Matrix Iterative Analysis, Richard S. Varga, Second Edition, Springer Berlin Heidelberg.

MAL 612– Nonlinear Analysis and Applications
[(3-0-0); Credit: 3]

Prerequisite: Functional Analysis and Fixed Point Theory
Course Objectives

The course learning objectives include the following:

1. To introduce the research students an advanced concepts and theorems of Functional Analysis and Fixed Point Theory.
2. To have a fundamentalunderstanding of some topological fixed point theorems and their applications.
3. To have a knowledge of applying the fixed point approaches in various existence problems.

Course Outcomes (COs)

The course learning outcomes include the following:

1. The students will be able to understand the importance of some topological fixed point theorems and their applications.
2. The students will be able to apply some fixed point resultsin solving various functional equations.
3. To understand the existence of best proximity point and the fixed point of multivalued mapping with their applications.
4. To have an ability of working on a research problem in the area of functional analysis and fixed point theory.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Contents (CO wise):
Extension theorem, retracter, Brouwer's fixed point theorem, compact operator, Schauder fixed point theorem, Peano's fixed point theorem; Applications: Existence principle for system of equations, integral equation with small parameters, existence principle for system of inequalities.

A measure of noncompactness, application to generalized interval nesting, condensing maps, operators with closed range and approximation of fixed points, Darbo and Sadovshiis fixed point theorem for condensing mappings, FPT's for perturbed operators, the Bourbahi-Kneser fixed point theorem, fixed point theoremof Amann and Tarshi; application differential equation in Banach space, interval arithmetic and formal languages.

Fixed points of multivalued mappings, generalized Schauder'sfixed point theorem, variational inequalities and Browder fixed point theorem, external principle, the min-max theorem and saddle point, application in game theory, selection and the marriage theorem, Michael's Selution theorem, application to the generalized Peano theorem for differential inclusion.

Best proximity point theorem and application, Ky-Fan best approximation theorem, introduction to best proximity point, cyclic contractions and best proximity point theorem, relatively nonexpansive mapping and best proximity theorem, proximal normal structure, application to system of differential structure, best proximity point theorem via measure of noncompactness, application to system of integral equation.

Reference Books:

1. Eberhard Zeidler, Nonlinear Functional Analysis and its Applications I: Fixed-Point Theorems, Springer-Verlag, 1986 edition.
2. W.A. Kirk and B. Sims, Handbook of metric fixed point theory, Kluwer Academic Publishers, 2001.
3. Q.H. Ansari, Nonlinear Analysis: Approximation Theory, Optimization and Applications, Birkhauser (Springer), 2014.
4. J.M. Ayerbe Toledano, T. Dominguez Benavides, G. Lopez Acedo, Measures of Noncompactness in Metric Fixed Point Theory: Volume 99 (Operator Theory: Advances and Applications), Birkhäuser; 1997 edition.
5. J. Banaś, M. Mursaleen, Sequence Spaces and Measures of Noncompactness with Applications to Differential and Integral Equations, Springer Nature; 2014 edition.

MAL 613 - Introduction to Ill-posed Operator Equations [(3-0-0); Credit: 3]

Prerequisite: Functional Analysis

Course Objectives:

1. To introduce the research student to advanced concepts and theorems of Functional Analysis and Operator Theory.
2. To expose student to basic concepts and theorems of linear and nonlinear ill-posed Operator equations.

Course Outcomes: After the completion of the course, student will be able

1. To understand the importance and applicability of theorems of Functional Analysis and Operator Theory.
2. To work on the research problems involved in the area of ill-posed operator equations.

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1												
CO2												
CO3												
CO4												
CO5												

Course content:

Basic Results from Functional Analysis: Spaces, Boundedoperators, Compactoperators,Uniformboundednessprinciple, Closed graph theorem, Hahn-Banachtheorem, ProjectionandRieszrepresentation theorems.

Adjoint of an operators,Invertibilityofoperators,Spectralnotions,Spectrumofacompactoperator,Spectral mapping theorem,Spectralrepresentationforcompactselfadjointoperators,Singularvalue representation, Spectraltheoremforself-adjointoperators.

Well-posedness and Ill-posed-ness, Examples of well-posed and ill-posedequations, Ill-posed-nessof operator equations,Compactoperatorequations,Abackwardheatconductionproblem, LRNsolution,Generalizedinverse,Normalequation, Picard Theorem.

Regularizationfamily,Regularizationalgorithm,TikhonovRegularization,Sourceconditionsandorderofconvergence, Errorestimates under Holder type source condition, Error estimate with inexact data,Anillustrationofthesourcecondition, discrepancyprinciples,Remarksongeneralregularization,Best possible worst case error,Estimatesfor$\omega(M,\delta)$,Illustration withdifferentiationproblem,Illustrationwithbackwardheatequation,General source conditions,ErrorestimatesforTikhonovregularization, parameter choicestrategies,Estimatefor$\omega(M_\varphi,\rho,\delta)$.

Iterative regularization methods, Landweber iteration, Accelerated Landweber methods.

Tikhonov regularization of nonlinear ill-posed problems, Iterative methods for ill-posed nonlinear problems.

Text Books:

(1)M. T Nair,Linear Operator Equations: Approximation and Regularization, World Scientific, Singapore, May 2009.

(2) Engl H W, Hanke M and Neubauer A : Regularization of Inverse Problems, Dordrecht: Kluwer, 1996.

MAL 614: Lie Groups and Lie Algebras to Ordinary Differential Equations

(Prerequisite: Real Analysis, Topology and Abstract Algebra)

[(3-0-0); Credit: 3]

Objective: The objective of this course is to introduce the concept of Lie groups and Lie algebras for solving ordinary differential equations analytically.

Contents(CO wise):

Introduction to Lie Groups:

Manifolds: Change of coordinates, maps between manifolds, submanifolds, regular and implicit submanifold. *Lie Groups:* Local Lie groups, local transformation groups. *Lie algebra:* Lie bracket, one parameter subgroups, 'r'-parameter subgroups, subalgebras, the exponential map, Lie algebras of local Lie groups, structure constants, commutator table, Infinitesimal group action, solvable Lie algebra.

Symmetry Groups of Differential Equation:

Symmetry of algebraic equations: Invariant subsets, Invariant functions, Infinitesimal invariance, Local invariance, method for constructing invariants. *Groups and Differential Equations:* prolongations (extended transformations), prolongations for one dependent one independent variable, one dependent, n-independent variables, m-dependent and n-independent variables.

Ordinary Differential Equations:

First Order ODEs: Canonical coordinates, integrating factor, mapping of solution curves, determining equations for symmetries, determination of 1^{st} order ODE invariant under given group. *Invariance of Second and Higher order ODEs under Point symmetries:* reduction of order through canonical coordinates, reduction of order through differential invariant, determining equations for point symmetries of n^{th} order ODE. Determination of n^{th} order ODE invariant under given group. *Contact symmetries and higher order symmetries:* determining equations for contact symmetries and higher order symmetries, examples of contact and higher order symmetries, reduction of order using contact and higher order symmetries. *Invariant solutions:* Invariant solutions for first and higher order ODEs.

Text Books/Reference Books:

1. P.J. Olver, Applications of Lie Groups to Differential Equations, Vol. 107, Springer Science & Business Media, New York, 2000.
2. G.W. Bluman, S. Anco, Symmetry and Integration Methods for Differential Equations, vol. 154, Springer Science & Business Media, New York, 2008.
3. G.W. Bluman, S. Kumei, Symmetries and Differential Equations, Springer Science & Business Media, New York, 1989.
4. L.V. Ovsiannikov, Group Analysis of Differential Equations, Academic Press, New York,1982.

MAL 615: Lie symmetry analysis to Partial Differential Equations

(Prerequisite: Applications of Lie Groups and Lie Algebras to Ordinary Differential Equations)

[(3-0-0); Credit: 3]

Objective: The main objective of this course is to construct exact solutions for partial differential equations through similarity transformations and study their physical behavior.

Contents (CO wise):

Partial Differential Equations:

Introduction: Invariance of PDEs with elementary examples. *Invariance for scalar PDEs:* Invariant solutions, determining equations for symmetries for k^{th} order PDEs, examples. *Invariance for system of PDEs:* Invariant solutions, determining equations for symmetries for system of PDEs, examples. *Applications to Boundary Value Problems:* Formulation of invariance of a BVP for scalar PDEs, incomplete invariance for linear scalar and system of PDEs.

Conservation Laws:

Local conservation laws, equivalent conservation laws, multiplier for conservation laws, direct method for construction of conservation laws, Linearizing operators and adjoint equations, fluxes of conservation laws, self adjoint PDE systems. *Noether's theorem:* Euler-Lagrange equations, Noether's formulation of Noether's theorem, limitations of Noether's theorem. Connection between symmetries and conservation laws.

Construction of Mappings Relating Differential Equations:

Introduction, mapping of a given PDE to a specific target PDE, invertible mappings of nonlinear PDEs to linear PDEs through symmetries, invertible mappings of linear PDEs to linear PDEs with constant coefficients, Invertible mappings of nonlinear PDEs to linear PDEs through conservation law multipliers,

Nonlocal Symmetries:

Nonlocally Related PDE Systems : Nonlocally related potential systems and subsystems, trees of nonlocally related PDE systems, nonlocal conservation Laws, extended tree construction procedure. *Applications of Nonlocally Related PDE Systems***:** Nonlocal symmetries, construction of non-invertible mappings relating PDEs.

Text Books/Reference Books:

1. G.W. Bluman, S. Anco, Symmetry and Integration Methods for Differential Equations, vol. 154, Springer Science & Business Media, New York, 2008.
2. Peter E. Hydon, Symmetry methods for differential equations: a beginner's guide, Cambridge University Press, 2000.
3. G. W. Bluman, A. F. Cheviakov, and S. C. Anco, Applications of Symmetry Methods to Partial Differential Equations (Springer, 2010), Vol. 168

MAL 616 – Fractal Approximation

[(3-0-0); Credit: 3]

Objective: The objective of this subject is to introduce fractals, construction of fractals, fractal interpolation, fractal splines and their convergence and fractal approximation.

Contents (CO wise):

Existence of Continuous and Nowhere Differentiable Functions, Construction of Continuous and Nowhere Differentiable Functions, Classical Fractals, Self-similarity, Metric Spaces.

Iterated Function System, Space of Fractals, Collage Theorem, Fractal Dimension, Fractal Interpolation Functions (FIFs), Fractal Splines, Hidden Variable FIF, Fractal Surfaces, Mandelbrot Set, Julia Set and Fatou Set.

Shape Preserving Fractal Splines, Constrained Fractal Splines, Fractal Approximation, Difference between Classical Approximation and Fractal Approximation, Hidden Variable Fractal Approximation, Shape Preserving Fractal Approximation.

Text Books/ Reference Books:

1. M.F. Barnsley, Fractals Everywhere, Academic Press, 1993.
2. K. Falconer, Fractal Geometry (Mathematical Foundations and Applications), John Wiley & Sons, 1990.
3. Peter Massopust, Fractal Functions, Fractal Surfaces, and Wavelets, Second Edition, Elsevier Science, 2016.

MAL 617 Fuzzy Set Theory and its Applications

[(3-0-0); Credit: 3]
Objective: The objective of this course is to introduce students to the areas of fuzzy set theory and its application in various fields (specially in Optimization).

Content (CO wise):

Fuzzy Mathematics: Introduction to Fuzzy sets, Crisp vs Fuzzy Types of Fuzzy sets, Membership functions, Alphacuts, Operation on fuzzy sets, t-norm, complements t-conorm, combination of operations continued, Introduction to Fuzzy arithmetic Interval arithmetic.
Fuzzy arithmetic using Alpha cuts continued Decomposition principle, Extension principle, Fuzzy arithmetic using Extension Principle, Fuzzy EquationsRelations, Introduction to fuzzy relations, Projections, Equivalence relation

Applications of Fuzzy Set Theory: Introduction to propositional Logic, Boolean Algebra Multi valued logic, Linguistic Variables, Fuzzy Logic, Fuzzy propositions (conditional and unconditional)Inference from conditional and qualified fuzzy propositions.
Decision Making in Fuzzy Environments, Fuzzy Decisions, Fuzzy Linear Programming, Symmetric Fuzzy LP, Fuzzy LP with Crisp Objective Function, Fuzzy Set Models in Logistics, Fuzzy Approach to the Transportation Problem.

Text Books/ Reference Books:

1. Zimmermann, Hans-Jürgen. Fuzzy set theory—and its applications. Springer Science & Business Media, 2011.
2. Klir, George, and Bo Yuan. Fuzzy sets and fuzzy logic. Vol. 4. New Jersey: Prentice hall, 1995.
3. Ross, Timothy J. Fuzzy logic with engineering applications. John Wiley & Sons, 2005.
4. Nguyen, H. T., Walker, C., & Walker, E. A. (2018). A first course in fuzzy logic. Chapman and Hall/CRC.