INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Mathematics

Subject Code: MAO-101 **Course Title**: Optimization Techniques

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** OEC

Course Outlines: OR models, case studies. Convex sets, Linear Programming Problems: Graphical Method, Simplex Method, Revised Simplex Method. Duality Theory, Dual Simplex Method, Sensitivity Analysis. All-Integer and Mixed-Integer Programming Problems, 0-1 Integer Programming. Transportation Problems and Assignment Problems. Game Theory: Rectangular Games, Graphical solution of $2 \times n$ and $m \times 2$ games, reduction to Linear Programming Problems. Sequencing and Scheduling: Processing of Jobs through Machines, CPM and PERT.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE/SCHOOL: Department of Mathematics

Subject Code: MAO-102 **Course Title:** Advanced Engineering Mathematics

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** OEC

Course Outlines: Functions of a complex variable: Analytic functions. Conformal Mappings: Bilinear transformations, Schwartz-Christoffel transformations. Complex Integration: Line integrals, Cauchy integral theorem, Taylor's and Laurent's expansions, zeros and singularities, Cauchy residue theorem, contour integration and its applications. Partial differential equations (PDEs): Solution of first order PDEs, classification of second order PDEs, solutions of one dimensional wave and diffusion equations, Laplace equation in 2 and 3 dimensions. Calculus of Variations: Functionals, Euler's equations for one and several variables, isoperimetric problems, sufficient conditions for weak and strong maxima and minima.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAT-101 **Course Title**: Numerical Optimization

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** TEB

Course Outlines: Review of Linear Programming, Nonlinear Programming and 1-D Unconstrained Minimization Methods, Multi-dimensional Unconstrained Minimization Methods: direct and indirect search methods, direct methods and indirect methods for constrained minimization, implementation of optimization algorithms using related software.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAT-102 **Course Title**: Non linear Programming

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** TEB

Course Outlines: Convex functions and their properties, differentiable convex functions, KKT necessary and sufficient optimality conditions. Quadratic programming problems, Wolfe's and complementary pivot methods. Separable programming problems, their solution methodology. Dynamic programming: discrete and continuous cases. Geometric programming. Multi-objective programming problems, Goal programming. Search techniques for unconstrained and constrained optimization problems.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAT-103 **Course Title:** Numerical Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** TEB

Course Outlines: Method of inflation, Jacobi, Givens and Householder methods for symmetric matrices, LR and QR methods, multistep methods for initial value problems, error and stability analysis, stiff problems and boundary value problems, finite difference methods, numerical methods for solving elliptic, parabolic and hyperbolic PDEs with error, convergence and stability analysis.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAT-104 **Course Title**: Finite Element Methods

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** TEB

Course Outlines: Piecewise polynomial spaces in 1D, interpolation, L^2 projection, FEM for two-point boundary value problem, Meshes, piecewise polynomial spaces in 2D, interpolation, L^2 projection, FEMfor Poisson's equations, basic analysis of FEM, heat equation, stability estimates, a priori estimates, a posteriori error estimates, wave equation, direct/iterative methods and preconditioning, interpolation of functions in Hilbert spaces, abstract finite element approximation, the non-linear Poisson equation, finite element approximation, the bistable equation, numerical approximation of the Jacobian.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAT-105 **Course Title**: Financial Mathematics

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** TEB

Course Outlines: Simple market model, hedging, speculation, arbitrage, present value, annuity, pricing of forward and future contracts, call and put options, put-call parity, European and American options, option bounds, trading strategies, Cox-Ross-Rubenstein model, risk-neutral valuation, complete market, fundamental theorem of asset pricing, Black-Scholes model, martingale and PDE approach to pricing, Greeks, extension of the models to dividends, currencies, etc., Vasicek model, Cox-Ingersoll Ross model.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAT-106 **Course Title**: Financial Risk Management

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** TEB

Course Outlines: Introduction to risk management, coherent risk measures, value-at-risk, expected shortfall, credit risk, credit default swap, basket default swap, collateral debt obligation, regularity capital, credit risk modeling, counterparty credit risk, credit and debt valuation adjustment, wrong/right way risk, time series modelling, ARMA, GARCH, stochastic volatility models, spectral analysis, copulas, Sklar's theorem, comonotonicity, extreme value theory.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAB-103 **Course Title:** Numerical Methods

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** BSC

Course Outlines: Introduction to error analysis and significant digits, direct and iterative methods for solving of system of linear equations, numerical methods for finding roots of nonlinear equations, power method for finding dominant and smallest eigenvalues and eigenvectors, interpolation methods, first and second order derivatives by various interpolation formulae, numerical integration, numerical solutions of first and second order ordinary differential equations.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAB-104 **Course Title**: Mathematical Methods

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** BSC

Course Outlines: Solution of linear ODEs with constant coefficients, Euler-Cauchy equations, solutionof second order ODEs by changing dependent and independent variables, method of variation ofparameters, series solution method, solution of first order partial differential equations: Lagrange's equation, Four standard forms of non-linear first order equations, Laplace transforms with applications, Z-transforms with applications for solving difference equations, Fourier series and Fourier transforms with their applications.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-201 **Course Title**: Operations Research

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Basics of linear programming problems, simplex method, Big-M method, revised simplex method, duality theory, sensitivity analysis, parametric LPP, cutting plane and branch-and-bound techniques for all integer and mixed integer LPPs, transportation problems, game theory, steady-state solutions of Markovian queuing models, inventory models.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-202 **Course Title**: Complex Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Algebra of complex numbers, simply connected and multiply connected domains, stereographic projection, functions of a complex variable, limits, continuity, uniform continuity, differentiability, analytic function, Cauchy-Riemann equations, harmonic functions, sequence and series, uniform convergence, power series, elementary functions, complex integration, Cauchy's theorem and Cauchy's integral formula, Morera's theorem, Liouville's theorem, maximum modulus principle, zeros and poles, residue calculus, conformal mappings.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-203 **Course Title**: Stochastic Calculus

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Basics of probability theory, conditional expectation, martingales, stopping time, martingale inequalities, Brownian motion and its properties, Ornstein-Uhlenbeck process, Itô's integral and its properties, stochastic differential equations, Itô's lemma and product rule.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-291 **Course Title**: Technical Communication

L-T-P: 2-0-0 **Credits:** 2 **Subject Area:** PCC

Course Outlines: Basic writing procedure in Mathematics, difference between Lemma, Proposition, Theorem and Corollary. Various procedures of writing mathematical proof, Latex writing and documentation, preparing mathematical presentations, introduction to mathematical software, statistical observations through spreadsheets, database management software, software tools for optimization technique.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-301 **Course Title:** Basic Abstract Algebra

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Introduction to groups and subgroups, various examples of groups, Lagrange's theorem, normal subgroups, isomorphism theorems. Group actions, Sylow's theorems, permutation groups. Introduction to rings, ideals, homomorphism of rings, prime and maximal ideals, polynomial rings, irreducibility of polynomials. Introduction to field extensions, algebraic extensions, ruler and compass constructions.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-302 **Course Title**: Theory of Differential Equations

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Existence, uniqueness and continuation of differential equations, homogeneous and nonhomogeneous linear systems of differential equations, boundary value problems for second order differential equations, Green's function, Sturm-Liouville problem, autonomous systems, stability analysis, first order PDEs with existence and uniqueness results, Cauchy's method of characteristics, second order PDEs, classification and canonical forms, elliptic equations, hyperbolic equations, parabolic equations, Duhamel's principle.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Mathematics

Subject Code: MAC-351 **Course Title:** Fundamentals of AI/ML

L-T-P: 3-1-0 **Credits:** 2 **Subject Area:** PCC

Course Outlines: Basics of machine learning, supervised and unsupervised learning, introduction to reinforcement learning, Bayesian decision theory, maximum likelihood and Bayesian parameter estimation, non-parametric ML techniques, linear discriminant analysis, neural networks and convolution neural networks, generative deep learning models, introduction to physics-informed machine learning.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-401 **Course Title:** Abstract Algebra

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Review of groups, group actions, class equation, Sylow's theorems, fundamental theorem of finite abelian groups. Review of basic ring theory, factorization in integral domains, principal ideal domains, Euclidean domains, unique factorization domains, polynomial rings over unique factorization domains. Modules, submodules and their direct sums, quotient modules, homomorphism of modules, cyclic modules, simple modules, free modules. Field extensions, splitting fields, normal and separable extensions, finite fields, Fundamental Theorem of Galois theory.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-402 **Course Title**: Topology

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Review of set theory, open sets, basis and sub-basis for a topology, Housdorff spaces, order topology, product topology, subspace topology, metric spaces and their topology, quotient topology, connected spaces, path connected and locally connected spaces, connected components, compact spaces, limit point compactness, local compactness, one-point compactification, countability axioms, separation axioms, regular and normal spaces, Urysohn's lemma, Urysohn metrization theorem, Tietze extension theorem, Tychonoff theorem.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-403 **Course Title**: Linear Algebra

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Review of vector spaces and basics of linear transformations, linear functional and annihilators, dual spaces, eigenvalues and eigenvectors, characteristic polynomial, annihilating polynomial, the minimal polynomial, Cayley-Hamilton theorem, triangulation, diagonalization, invariant subspaces, Jordan canonical form, rational canonical form, inner product spaces, orthogonal projections, positive definite, adjoint and self-adjoint, unitary and normal operators, spectral theorem on finite dimensional vector spaces, singular value decomposition, symmetric and skew-symmetric bilinear forms, real quadratic forms, Sylvester's law of inertia.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-404 **Course Title:** Functional Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Normed linear spaces, Banach spaces, inner product spaces, Hilbert spaces, convex sets, projection theorem, orthogonal and orthonormal systems in Hilbert spaces, Bessel's inequality, Parseval's inequality, continuity of linear maps on normed linear spaces, linear bounded operators and respective norms, conjugate and dual spaces, Riesz representation theorem, compact operators; adjoint operators, normal operators and unitary operators on Hilbert spaces, the Closed Graph Theorem, the Uniform Boundedness Principle, the Hahn-Banach extension and separation theorems, Open Mapping Theorem.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-405 **Course Title**: Real Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Derivatives in several variable calculus, Clairaut's theorem, the inverse function theorem, the implicit function theorem, integration on n-dimensional Euclidean plane, Stokes' Theorem. Metric spaces, convergence of sequences, open and closed subsets, continuity, Cauchy sequences, completeness, Baire category theorem, contraction mapping theorem, connectedness, compactness, Heine-Borel theorem. Weierstrass approximation theorem, review of the Riemann and the Riemann-Stieltjes integrals, fundamental theorem of calculus, first and second mean value theorems. Inner and outer measures, measurable sets, measurable functions, Lebesgue integration.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTRE: Department of Mathematics

Subject Code: MAC-407 **Course Title**: Real and Functional Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PCC

Course Outlines: Topology of metric spaces, uniform convergence, continuous maps, compactness, completeness and completions, contraction mapping theorem, Weierstrass approximation theorem, normed linear spaces, Banach spaces, continuity and boundedness of linear functionals, dual spaces, bounded linear operators, inner product spaces, Hilbert spaces, orthogonal decomposition, Fourier series, orthogonal and orthonormal systems in Hilbert spaces, convergence of orthogonal series, Bessels's inequality, orthonormal bases, Parseval's identity, Riesz representation theorem, Hahn-Banach theorem, reflexive spaces, the Uniform Boundedness Principle and its applications.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-411 **Course Title:** Analytic Number Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Review of complex analysis, arithmetic functions, distribution of primes, Gauss sums, Dirichlet series and Euler products, Riemann Zeta function, Dirichlet L-functions, modular forms, Eisenstein series, cusp forms, structure of the ring of modular forms, Hecke operators and Euler product for modular forms, the L-function of a modular form, functional equations, modular forms and the sums of four squares.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-412 **Course Title:** Combinatorial Mathematics

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Basic counting principles, pigeonhole principle, principle of inclusion and exclusion, derangements, inversion formulae, generating functions, recurrence relations, Catalan numbers, difference sequences, Stirling numbers, integer partitions, systems of distinct representatives, Polya's theory of counting, Design theory: Latin squares, BIBDs, symmetric designs, Steiner triple systems, resolvable BIBDs, Hadamard matrices and designs, *t*-designs.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-413 **Course Title:** Credit Risk Modeling

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Credit risk, counterparty credit risk, firm value approach and reduced-form approach, Structural model for corporate debt, risk neutral valuation, PDE approach, Merton's model with deterministic and stochastic interest rates, First Passage Time Models, Black and Cox model, Hazard Processes, Reduced-form approach.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-414 **Course Title:** Differential Geometry

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Curves, Frenet-Serret frame and formula, osculating circle, Hopf's Umlaufsatz theorem, surfaces, level sets, tangent spaces at a point, smooth vector fields, integral curve of a vector field, normal field, orientation, Gauss map, geodesic on a surface, covariant derivative of a vector field, Weingarten map of a surface at a point, and its self-adjoint property, normal curvature, principal curvatures, first and second fundamental forms, Gauss curvature and mean curvature, surfaces with boundary, Stokes theorem, Gauss-Bonnet theorem, Alexandrov's lemma.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-415 **Course Title:** Design and Analysis of Algorithms

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Asymptotic notations, best and worst case running time complexities, loop-invariant method for correctness, probabilistic analysis, amortized analysis, divide and conquer algorithms, recurrence relations, master theorem, dynamic programming based algorithms, greedy algorithms, algorithms for graphs, string matching, computational complexity theory.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-416 **Course Title:** Graph Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Introduction to graphs, graph as a model, bipartite graph, graphic sequence, trees, spanning trees, Euler graphs, Hamiltonian graphs, planar graphs, vertex coloring of graphs, directed graphs, Ramsey theory.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-417 **Course Title:** Mathematical Image Processing

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Basics of digital images, connectivity and adjacency relationships between pixels, pixel-based image enhancement, spatial domain filtering, discrete and fast Fourier transforms, sampling, frequency domain filtering, image restoration, linear and position invariant degradation, Wiener and Least-Square filters, Perona-Malik method, wavelets and multiresolution analysis, morphological operations for binary and gray-level images, feature detection algorithms, ML/DL methods for image recognition.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-418 **Course Title:** Mathematical Modeling and Simulation

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Introduction to mathematical modeling, mathematical models and functions, dimensional analysis, continuous models, discrete models, numerical solutions of the discrete and continuous models and its graphical representation using mathematical software tools, modeling and simulation concepts, parameter estimation for discrete and continuous models, verification and validation of simulation models.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-419 **Course Title:** Number Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Euclidean algorithm, linear Diophantine equations, prime numbers, Fundamental Theorem of Arithmetic, congruences, solutions of linear congruences, Chinese remainder theorem, Euler's totient function, Hensel's lemma, primitive roots and power residues, quadratic residues, quadratic reciprocity, finite continued fractions, infinite continued fractions, introduction to cryptography.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-420 **Course Title:** Statistical Machine Learning

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Theory of statistical learning, dimension reduction algorithms, supervised learning: classification and regression algorithms, resampling methods and regularization, decision trees, ensemble learning algorithms, unsupervised learning algorithms, density estimation, introduction to deep learning algorithms.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-511 **Course Title:** Abstract Harmonic Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Basic concepts, Gelfand theory, nonunital Banach algebras, spectral theorem, theory of representation. Topological groups, Haar measure, modular functions, convolutions, homogenous spaces. Dual group, Pontragin Duality Theorem, closed ideals, spectral synthesis, Bohr compactification, Peter-Weyl Theorem, Fourier analysis. Unitary representation, representation of a Group and its group algebra, functions of positive type, induced representations, Frobenius Reciprocity Theorem, pseudo measures, imprimitivity. Group C* algebra, structure of dual space, tensor products, direct integral decomposition, Planchelar Theorem.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-512 **Course Title:** Advanced Complex Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Review of complex integration. Conformal mappings and their applications. analytic continuation, standard method of analytic continuation. Meromorphic functions, Harmonic functions, Entire functions with their properties and applications.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-513 **Course Title:** Advanced Matrix Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Block matrices, determinant and inverse of block matrices, the continuity argument, factorization of matrices, special types of matrices and their properties, matrix inequalities, majorization and its applications in combinatorial analysis, Birkhoff's theorems, Schur's theorem, the minimax principle for eigenvalues and for singular values, Cauchy's interlacing theorem, Poincare inequality, Weyl's inequality, Weyl's motonocity and perturbation theorems, Lidskkii's theorems, different kind of matrix norms, matrix/operator monotone, convexity and their characterizations.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-514 **Course Title:** Advanced Numerical Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Introduction to finite element methods (FEM) for Poisson problems, mixed FEM for Stokes equations, FEM for convection- diffusion problems, mixed FEM for Navier-Stokes equations, a priori error bounds, a posteriori error bounds, Solutions of corresponding discrete problems, Solution of unsteady Navier-Stokes equations.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-515 **Course Title:** Advanced Operations Research

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Convex functions and their properties, generalizations of convex functions, The Fritz-John and the Karush-Kuhn-Tucker optimality conditions, cone of tangents, polar cone and constraint qualifications. Convex quadratic programming problems, Wolfe's and Beale's methods, linear fractional programming problems, Charnes and Cooper method. Separable programming, geometric programming, dynamic programming, multi-objective programming problems and its solution concepts, goal programming problems, weighted sum approach.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-516 **Course Title:** Advanced Partial Differential Equations

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Transport equation, Laplace equation, heat equation, wave equation over R^n, Nonlinear first-order PDE, complete integrals, conservations laws, separation of variables, similarity solutions, transform methods, asymptotics, power series, test functions, distributions, fundamental solutions, Fourier transform, Schwartz space, tempered distributions.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-517 **Course Title:** Algebraic Number Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Review of field theory, integrality, integral closure, ring of integers, integral basis, discriminant, ideals, Dedekind domains, unique factorisation of ideals, fractional ideals, decomposition group, inertia group, lattices, Minkowski theory, norm of an ideal, ideal class group, the class number and finiteness, Dirichlet's unit theorem, valuations and completions of number fields, Ostrowski`s theorem, Hensel`s lemma, unramified, totally ramified and tamely ramified extensions of *p*-adic fields.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-518 **Course Title:** Algebraic Topology

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Fundamental groups and covering spaces, Van Kampen's theorem, homotopy lifting and extension properties, universal cover, classification of covering spaces, Deck transformations, categories and functors, simplicial sets and their geometric realizations, combinatorial models of topological spaces, singular homology groups, axiomatic properties, Mayer-Vietoris sequence, excision, universal coefficient theorem, degree theory, Euler characteristics, Lefschetz fixed point theory and its applications, CW-complexes and Cellular homology.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-519 **Course Title:** Approximation Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Concept of best approximation in a normed linear space, Different polynomials and approximation theorems, Modulus of continuity and trigonometric polynomials of best approximation, Positive linear operators with properties and applications.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-520 **Course Title:** Coding Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Block codes, linear codes, generator and parity-check matrices, Hamming codes, Golay codes, Reed-Muller codes, Bounds on codes, perfect codes, MDS codes, weight distributions of codes, MacWilliams identities. Finite fields, cyclic codes, BCH codes, Reed-Solomon codes, quadratic residue codes. Graphical codes, convolutional codes.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-521 **Course Title:** Commutative Algebra

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Commutative rings, the spectrum of a ring, affine algebraic set, Zariski topology. Review of modules, Nakayama's lemma, exact sequences, tensor product of modules, rings and modules of fractions, primary decomposition, integral extensions, Noether normalization theorem, Hilbert's nullstellensatz, Noetherian rings, Artinian rings, valuation rings, discrete valuation rings, Dedekind domains, fractional ideals, completions, dimension theory.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-522 **Course Title:** Computational Fluid Dynamics

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Review of finite difference methods for solving PDEs, Grid generation by algebraic mapping with numerical implementation, Basic CFD techniques, Vorticity-stream function approach, Upwind scheme, Quick scheme, Developments of MAC method, Finite volume methods, SIMPLE algorithm for calculation of the flow field, Spectral element method and its application to some benchmark problems**.**

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-523 **Course Title:** Control Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Mathematical models of control systems. Controllability, Kalman theorem, controllability Grammian, observability, duality theorems, controllability and observability results for discrete systems, feedback control. Liapunov stability, stability analysis for linear systems, Liapunov theorems for stability and instability for nonlinear systems, stabilizability and detachability; State feedback of multivariable system, Riccatti equation, optimal control for linear and nonlinear control systems; Control systems on Hilbert spaces, semigroup theory and control of a linear system.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-524 **Course Title:** Dynamical Systems

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Linear Dynamical Continuous Systems: Existence uniqueness theorems, *n*-dimensional linear systems, equilibrium points, stability, phase space, stable, unstable and center spaces. Nonlinear Autonomous Systems: local and global stability, Liapunov method, periodic solution, limit cycle, attractors, index theory, nonhyperbolic critical points, center manifolds, normal forms, gradient and Hamiltonian systems. Local Bifurcation: saddle node, pitchfork, transcritical bifurcation, Hopf bifurcation, co-dimension. Discrete Systems: Logistic maps, equilibrium points, stability, cycles, period doubling, chaos. Deterministic Chaos: Duffing's oscillator, Lorenz System, Liapunov exponents, routes to chaos.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-525 **Course Title:** Fluid Dynamics

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Basic concepts of fluid motion, Eulerian and Lagrangian approaches, boundary conditions, stream, path and streak lines, Bernoulli's theorem, Kelvin's theorem, complex-potential, source, sink and doublet, theorem of Blasius, continuity of mass, Helmholtz's vorticity equation, Reynolds transport theorem**,** Navier-Stokes equations, energy equation, Couette, Poiseuille and annular flows, dynamical-similarity, dimensional analysis, boundary layer equations, similarity solutions.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-526 **Course Title:** Fourier Analysis and Applications

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Fourier series and its convergence properties; Bernoulli polynomials, the isoperimetric problem, Jacobi's identity for the theta function, Weierstrass approximation theorem, Wallis product formula, Weyl's equi-distribution theorem; Fourier transform on the Schwartz space, Fourier transform on $L^1(\mathbb{R})$ and $L^2(\mathbb{R})$, spectral analysis of Fourier transform. Solution of differential equations and summation formulae; The central limit theorem, Heisenberg's uncertainty principle, Wiener theorem. Band- and Time-limited functions, Hardy's theorem, Paley-Wiener theorem, Shannon sampling theorem.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-527 **Course Title:** Fuzzy Sets and Fuzzy Systems

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Fuzzy sets, α- cuts, convex fuzzy sets, operations on fuzzy sets, Type-2 fuzzy sets, fuzzy numbers and extended operations on fuzzy numbers, LR- representations of fuzzy sets, *t*-norms and *t*-conorms, increasing and decreasing generators, interval equations, fuzzy equations, fuzzy relations on fuzzy sets, fuzzy functions and their extrema, differentiation and integration of fuzzy functions, fuzzy measures and measures of fuzziness, linguistic variables, uncertainty modeling in expert systems, fuzzy control, fuzzy LPP, fuzzy transportation and assignment problems, fuzzy dynamic programming, fuzzy multi-criteria analysis.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-528 **Course Title:** Hyperbolic Conservation Laws

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: First order partial differential equations (PDEs), methods of characteristics, well-posedness of Cauchy problems, hyperbolic conservation laws, discontinuous solutions, shock waves, Riemann problem for convex and non-convex fluxes, admissible entropy solution, hyperbolic system of first order PDEs, numerical schemes for conservation laws.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-529 **Course Title:** Integral Equations and Calculus of Variations

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Volterra and Fredholm equations, Fredholm theory, the Hilbert-Schmidt theorem, singular integral equations, Abel's integral equations, Cauchy type integral equations, functionals, extremum, variations, necessary condition for an extremum, Euler-Lagrange equation, General variation, variational problems with moving boundaries, broken extremals, Weierstrass-Erdmann conditions, second variation, weak and strong extremum.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-531 **Course Title:** Mathematical Biology

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: An overview of mathematical biology and the modeling process, continuous models, qualitative analysis of continuous models, phase plane analysis, bifurcations, limit cycles, spatial models, overview of difference equations, discrete models, notion of periodic points and cycles, existence and stability conditions of two cycles, numerical solution of the models and its graphical representation (both continuous and discrete).

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-532 **Course Title:** Mathematical Cryptography

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Introduction, classical cryptography; Shannon's theory, perfect secrecy. Fast exponentiation, finite fields, computational complexity. Public key cryptography: the discrete logarithm problem (DLP), Diffie-Hellman key exchange, the ElGamal cryptosystem, the RSA cryptosystem. Primality testing, Miller-Rabin test; Factoring algorithms. Algorithms for computing discrete logarithms; Cryptographic hash functions, digital signatures; Elliptic curves over finite fields, the elliptic curve discrete logarithm problem (ECDLP), elliptic curve cryptography.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-533 **Course Title:** Measure Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Measure on the real line, integration of Functions of a real variable, Lebesgue Integral, Fatou's Lemma, Lebesgue Monotone Convergence theorem, The General Integral, Lebesgue dominated convergence theorem, differentiation, abstract measure spaces, integration and L^p spaces, signed measures, Hahn and Jordan decompositions, and their derivatives, complex measures.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-534 **Course Title:** Multivariate Techniques

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Multi-variate normal distribution, linear regression models, estimation, confidence interval, test of significance, multiple regression analysis, partial F and multiple F test, partial and multiple correlation, confounding and interaction in regression, regression diagnostics, residual analysis, collinearity, polynomial regression, ANOVA, Gauss Markov theorem, analysis of variance using linear models.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-535 **Course Title:** Numerical Linear Algebra

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Review of direct and iterative methods for linear systems, matrix factorization algorithms, Nonsymmetrical eigenvalue problem, canonical forms, perturbation theory, projection methods, additive and multiplicative processes, Krylov subspaces, Arnoldi's method, GMRES, symmetric Lanczos algorithms, CG algorithm, methods related to normal equations, preconditioned iterations, preconditioning techniques.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-536 **Course Title:** Operator Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Geometry of Hilbert spaces, some classes of bounded linear operators, isometries, partial isometries, multiplication operators, finite rank operators, compact operators, spectrum and resolvent set, numerical radius, spectral radius, spectral mapping theorem, polar decomposition theorem, spectral theorem and singular value representation of a compact self-adjoint and normal operators, trace class operators, Hilbert-Schmidt operators, spectral measure, spectral integrals, spectral theorem for bounded self-adjoint and normal operators, reproducing kernel Hilbert spaces, Hardy space, Dirichlet space, Bergman space, Beurling's theorem.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-537 **Course Title:** Optimal Control Theory

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: General optimal control problems, controllability of linear equations, observability, bang-bang principle; Variational approach, necessary conditions for optimal control, Hamiltonian, Pontryagin's principle for continuous and for bounded and discontinuous controls, transversality conditions. Dynamic programming approach, optimal control law, principle of optimality and its applications to decision making in optimal control problems; Differential games, penalty and barrier search techniques, sensitivity analysis in optimal control problems.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-538 **Course Title:** Orthogonal Polynomials and Special Functions

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Gamma functions their properties and applications; Hypergeometric functions and their applications; Generalized hypergeometric function; Asymptotic series; Orthogonal polynomials their classification, properties and applications.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-539 **Course Title:** Portfolio Optimization

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Mean variance portfolio theory, efficient frontier, CAPM, multi-period CAPM, multi-beta CAPM, consumption CAPM, Single-index model, estimating beta, Multi-Index model, average correlation models, mixed models, fundamental multi-index models, determining the efficient frontier, APT, Efficient Market Theory.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-540 **Course Title:** Regularization Theory for Inverse Problems

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: A revisit of functional analysis, linear and nonlinear inverse problems, solutions of linear inverse problems, regularization theory, parameter choice rules, continuous regularization methods, Tikhonov regularization, iterative regularization methods.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-541 **Course Title:** Representation Theory of Finite Groups

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Representations, Schur's lemma, complete reducibility, Maschke's theorem, group algebras, modules over group algebra, conjugacy classes, character of a representation, class functions, orthogonality relations for characters, permutation representations, regular representation, number of irreducible representations, explicit decompositions, induced representations, integrality properties of characters, Frobenius reciprocity theorem.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-542 **Course Title:** Semigroup Theory and Applications

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Generation and representations, uniformly continuous semigroup, C_0-semigroup, Hille-Yosida theorem, characterization of the infinitesimal generator of C_0-semigroup; Abstract Cauchy problem, regularity of mild solutions for analytic semigroups; Evolution equations, stable families of generators, evolution systems in hyperbolic and parabolic Cauchy problems, homogeneous and inhomogeneous equations; Applications to parabolic equations, wave equation, and Schrodinger equation.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-543 **Course Title:** Sobolev Spaces and Applications

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Weak derivatives, definition and basic properties of Sobolev spaces, approximation by smooth functions, extension theorems, Poincaré's inequality, Sobolev's embedding theorems, compactness theorems, trace theory, spaces involving time, second order elliptic, parabolic and hyperbolic equations, weak solutions, regularity, nonlinear reaction-diffusion equations.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-544 **Course Title:** Statistical Inference

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Point estimation**,** unbiasedness, consistency, efficiency, method of Moments, MLE, sufficiency, factorization theorem, completeness, testing of hypothesis, Cramer-Rao bound, UMVBE, interval estimator, Neyman-Pearson lemma, likelihood ration principle, SPRT, Bayesian inference, loss and risk function, Bayes risk and estimators, importance sampling, non-parametric inference, run test, sign test, Wilcoxon signed test, Kolmorogov-Smirnov test.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-545 **Course Title:** Stochastic Differential Equations

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Brownian motions, stochastic integrals, Itô's formula, stochastic differential equations (SDE), existence and uniqueness of solutions, Relations between SDE and PDE, Feynman-Kac formula, solutions as Markov processes, generators and martingale problem, Stability of stochastic differential equations, stochastic stabilization and destabilization, backward stochastic differential equations (BSDE), BSDE and quasilinear PDE.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-546 **Course Title:** Stochastic Partial Differential Equations

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Hilbert space valued random variables and their integrals, Kolmogorov continuity criterion, processes with filtration, martingales in Hilbert spaces, Hilbert space valued Wiener processes, stochastic integral for generalized Wiener processes, properties of the stochastic integral, Ito's formula, linear equations with additive and multiplicative noise, existence and uniqueness of solutions, continuity and regularity of solutions, existence and uniqueness for nonlinear equations, equations with Lipschitz nonlinearities, additive and multiplicative noise cases, strong, weak, martingale and mild solutions.

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPARTMENT/CENTER/SCHOOL: Department of Mathematics

Subject code: MAL-547 **Course Title:** Wavelet Analysis

L-T-P: 3-1-0 **Credits:** 4 **Subject Area:** PEC

Course Outlines: Fourier analysis, short-time Fourier transform, wavelet transform and its basic properties, discrete wavelet transforms, orthonormal wavelets, wavelet frames and multiband, curvelets, scaling functions and wavelets: definition of multiresolution analysis and examples, Daubechie's wavelets and algorithms.