Course Structure & Syllabus

of

Two Year Applied Master of Science

in

Mathematics

(Session 2019 – 2020 Onward)

Department of Mathematics

Veer Surendra Sai University of Technology (VSSUT)

Siddhi Vihar, P.O.: Engineering CollegeBurla,

Sambalpur–768018, Odisha, India

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VISION

The Department of Mathematics strives to be internationally recognized for its academic excellence through the depth of teaching and research, and making students technologically and mathematically competent with strong ethics contributing to the rapid advancement of the society.

MISSION

M1. To transform young people to competent and motivated professionals.

M2. To produce PG students with strong foundation to join research or serve in academics.

M3. To cater to the development of the nation, particularly in Odisha for research and training.

PROGRAMME EDUCATIONAL OBJECTIVES (PEOs)

The program educational objectives of Applied M. Sc. in Mathematics are:

1. To provide a post graduate course, suitable for students of high ability, combining and relating mathematics, science and technology.
2. To prepare graduates for further study and research, particularly in areas requiring the application of mathematics.
3. To enrich students with a knowledge of mathematics, its research potential and the interaction between them.

PEO-MISSION MATRIX

	M1	M2	M3
PEO1	3	2	1
PEO2	1	3	2
PEO3	2	2	3

PROGRAMME OUTCOMES (POs)

The Program Outcomes of Applied M.Sc. in Mathematics are:

PO1	An ability to independently carry out research/investigation and development work to solve practical problems.
PO2	An ability to write and present a substantial technical report/document
PO3	An ability to demonstrate a degree of mastery over Applied Mathematics which is at a level higher than the requirements in the undergraduate program in Mathematics.
PO4	An ability to identify, analyze and formulate complex mathematical problems to reach logical conclusion.
PO5	An ability to apply knowledge of Mathematics in different field of science and technology.
PO6	An ability to recognize the need for and to ready for lifelong learning to keep updated on technological changes.

Program Specific Outcomes (PSOs)

PSO1	Design and analyze the mathematical models for the problem related to science, technology, and other socio-economic world.
PSO2	Apply knowledge of Mathematics in different fields of science & technology, and to provide an opportunity to pursue careers in research and development, teaching and allied areas related to Mathematical Science.

Course Structure of 2 Year Applied M. Sc. (Mathematics)

CourseCode	Name of the Course	L–T–P	Credit
	FIRST SEMESTER		
MMA01001	Real Analysis	3–1–0	04
MMA01002	Differential Equation	3–1–0	04
MMA01003	Linear Algebra	3–1–0	04
MMA01004	Data Structure using C	3–1–0	04
MMA01005	Data Structure Lab	0–0–3	02
----	Comprehensive viva		02
MCAC ----	Audit I		00
		Total Credits	**20**

SECOND SEMESTER

MMA02001	Measure Theory and Integration	3–1–0	04
MMA02002	Complex Analysis	3–1–0	04
MMA02003	Topology	3–1–0	04
MMA02004	Numerical Analysis	3–1–0	04
MMA02005	Numerical methods using MATLAB	0-0-3	02
---	Seminar		02
MCAC ---	Audit II		00
		Total Credits	**20**

THIRD SEMESTER

MMA03001	Functional Analysis	3–1–0	04
MMA03002	Abstract Algebra	3–1–0	04
----	Elective I	3–1–0	04
----	Open Elective	3–1–0	04

----	Seminar		02
----	Dissertation–I		02
		Total Credits	**20**

FOURTH SEMESTER

MMA04001	Operations Research	3–1–0	04
----	Elective II	3–1–0	04
-----	Elective III	3–1–0	04
-----	Industrial training/ Review/Internship training		02
-----	Dissertation–II		02
		Total Credits	**16**

Total Credit = 20+20+20+16 = 76

List of Elective Courses (Elective-I) for 3rd Semester

MMAPE301	Statistical Method	3–1–0	04
MMAPE302	Mathematical Modelling	3–1–0	04
MMAPE303	Partial Differential Equation	3–1–0	04
MMAPE304	Operator Theory	3–1–0	04
MMAPE305	Analytic Number Theory	3–1–0	04

List of Open Elective Courses for 3rd Semester

MMAOE301	Discrete Mathematical Structure	3–1–0	04
MMAOE302	Matrix Algebra	3–1–0	04
MMAOE303	Graph Theory	3–1–0	04

List of Elective Courses (Elective-II & III) for 4th Semester

	Elective-II		
MMAPE401	Cryptography	3–1–0	04
MMAPE402	Vector Optimization	3–1–0	04

MMAPE403	Applied Fluid dynamics	3–1–0	04
MMAPE404	Advanced Abstract Algebra	3–1–0	04
	Elective-III		
MMAPE405	Wavelet	3–1–0	04
MMAPE406	Data Science	3–1–0	04
MMAPE407	Advanced Complex analysis	3–1–0	04
MMAPE408	Machine Learning	3–1–0	04

Audit course 1 & 2

Sl.No.	Course Code	Subject Name
1.	MCAC---	English for Research Paper Writing
2.	MCAC---	Disaster Management
3.	MCAC---	Sanskrit for Technical Knowledge
4.	MCAC---	Value Education
5.	MCAC---	Optimization Technique
6.	MCAC---	Stress Management by Yoga
7.	MCAC---	Constitution of India
8.	MCAC---	Pedagogy Studies
9.	MCAC---	Personality Development through Life Enlightenment Skills.
10.	MCAC---	Computational and Statistical Method
11.	MCAC---	Application of GIS

FIRST SEMESTER

MMA01001 REAL ANALYSIS 4 Credits [3-1-0]

Module–I

Sequences: Sequences and their limits, monotone sequences, Bolzano-Weierstrass theorem for sequence, Cauchy Sequence, Cauchy criterion for convergence

Series: Introduction to Infinite series, convergence and absolute convergence, tests for absolute convergence, tests for non-absolute convergence

Module–II

Continuity: Continuous function and composition, continuous functions on intervals, intermediate value theorem, fixed point theorem, uniform continuity

Differentiability:Mean value theorem, Taylor's theorem, convex function

Module–III

Riemann integration: Riemann integral, Riemann integrable functions, fundamental theorem, Darboux's theorem.

Improper Integral: Basic concept of convergence of improper integrals

Module-IV

Sequences and series of functions: Point wise and uniform convergence, consequences of uniform convergence, power series, Weierstrass approximation theorem

Module-V

Function of several variables: differentiability, directional derivative, the matrix of linear function, Jacobian matrix, sufficient condition for differentiability, Taylor's formula.

Reference Books:

1. Introduction to Real Analysis, R. G. Bartle, Wiley
2. Principle of Mathematical Analysis, W. Rudin, Tata Mc Graw Hills
3. Apostol T.M.: Mathematical Analysis, Narosa Publishing House, and Indian edition.

Course Outcomes:

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

CO1	Evaluate the convergence or divergence of sequences and series
CO2	Analyze continuity and uniform continuity of functions
CO3	Develop knowledge of Riemann integral and improper integral
CO4	Incorporate uniform convergence of sequences and series of functions
CO5	Demonstrate the concept of differentiability for functions of several variables

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA01002 **DIFFERENTIAL EQUATIONS** **4 Credits [3-1-0]**

Module-I

Higher-order linear differential equations with constant and variable coefficients, Wronskian, system of first-order equations, existence and uniqueness theorem for system of linear ODEs,

Module -II

Fundamental Matrix, non-homogeneous linear systems, linear system with constant and periodic coefficients.

Module -III

Successive approximation, Picard's theorem, existence of solutions in the large, existence and uniqueness of solution of systems.

Module -IV

Sturm's Comparison theorem, elementary linear oscillations, comparison theorem of Hille-Wintner, oscillations of $x'' + a(t)x = 0$.

Module -V

Strum Liouville'sproblem with applications, Green's functions with problems

Reference Books:

(1) S.G. Deo, V. Raghavendra: Text book of Ordinary Differential Equations, Tata McGraw-Hill Ltd. New Delhi.

(2) G. Birkhoffand G.C. Rota: Ordinary Differential Equations, Wiley, New York.

Course Outcomes:

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

CO1	Identify the type of a given differential equation and apply the appropriate analytical technique for finding the solution of higher order ordinary differential equations
CO2	Develop the solution of Non-Homogeneous linear system of equations
CO3	Express the existence and uniqueness of solution of the system of equations
CO4	Analyze the behavior of the solution of second order ordinary differential equations
CO5	Demonstrate the solution of boundary value problems

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA01003 LINEAR ALGEBRA 4 Credits [3-1-0]

Module-I

Row transformations, rank of a matrix, systems of linear equations, existence and uniqueness, Gaussian elimination, vector spaces over fields, subspaces, basis and dimension,

Module –II

Linear transformations: Matrix Representation of Linear Map, change of basis matrix, rank-nullity theorem, inner product space and orthogonality, Gram Schmidt orthogonalization process.

Module -III

Eigenvalues and eigenvectors, characteristic polynomials, minimal polynomials, Cayley-Hamilton theorem, diagonalization, similarity

Canonical Form: triangulation form, Jordan canonical form, rational canonical form, quotient spaces.

Module -IV

Linear functional and dual space, annihilators, transpose of linear map, bilinear forms, symmetric and skew-symmetric bilinear forms, real quadratic forms, Hermitian form.

Module-V

Adjoint operator, self- adjoint operator, orthogonal and unitary operator, change of orthonormal basis, positive definiteness and positive operator.

Reference Books:

1. K. Hoffman and R. Kunze, Linear Algebra, Pearson Education (India), 2003. Prentice-Hall of India, 1991
2. Linear Algebra, Seymour Lipschutz and Marc Lipson, Schaum‘s Outline
3. S. Lang, Linear Algebra, Undergraduate Texts in Mathematics, Springer-Verlag, New York, 1989.
4. P. Lax, Linear Algebra, John Wiley & Sons, New York, Indian Ed. 1997
5. S.K. Paikray, Textbook of Matrix algebra, Kalyani publisher.

Course Outcomes:

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

CO1	Develop the solution of linear equations, and recognize the basic concepts of vector spaces
CO2	Apply rank-nullity theorem, construct orthogonal vectors, illustrate inner product spaces
CO3	Describe eigenvalues, eigenvectors and various canonical forms
CO4	Analyze the concept of dual space, describe various bilinear forms
CO5	Demonstrate various operators based on its properties

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA01004 DATA STRUCTURE USING C 4 Credits [3-1-0]

Module–I

Introduction: Data Structure in C,basic concepts ofsample data structure in C, Simple C code related to data structurer.

Constants, Variables and data types: Introduction, character set, C-tokens, key words and identifiers, constants, variables, data types, declaration of variables, assigning values to variables.

Operators and Expressions: Introduction, arithmetic, relational, logical, assignment, increment and decrement and special operators, arithmetic expressions, evaluations of expressions, precedence of arithmetic operators, operator precedence and mathematical functions. Managing input and output operators

Module–II

Introduction, decision making with IF statement, simple IF statement, the IF-ELSE statement, nesting of IF-ELSE statement, the ELSE-IF ladder, the SWITCH statement, the operator, GOTO statement. Decision making and Looping: Introduction, the WHILE statement, the DO statement, FOR statements.

Module–III

Arrays: Introduction, one dimensional arrays, two dimensional arrays, initializing two dimensional arrays, multi-dimensional arrays.

User defined functions: Introduction, need for user defined functions, a multi-function program, the form of C-functions, return values and their types, calling a function, category of functions, no arguments and no return values, arguments but no return values, arguments with return values, handling of non-integer functions, nesting of functions,recursion, function with arrays.

Module–IV

Structures and Unions: Introduction, structure definition, giving values to members, structure initialization, comparison of structures, variables, arrays of structures, structures within structures, structures and functions, unions, size of structures, bit fields.

Pointers: Introduction, understanding pointers, accessing the address of variables, declaring and initializing pointers, accessing through its pointers, pointer expression, pointer increments and scale factor, pointers and arrays, pointer and character strings, pointer and function.

Module–V

Dynamic memory allocation and Linked lists: Introduction, dynamic memory allocation, concepts of linked lists, and advantage of linked lists, types of linked lists, pointers revisited, basic test operators, and application of linked lists.

The Preprocessors: Introduction, macro substitution, file inclusion, compiler control directives, ANSI addition.

Recommended Book:

1. E. Balagurusamy, “Programming in ANSI C’, Tata Mc Graw Hill, Publishing Company Ltd., (2nd edition), New Delhi.

Course Outcomes:

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

CO1	Define different logical operators
CO2	Apply different logical operators in simple programs.
CO3	Recognize different data structures (array) to store different kinds of data
CO4	Implement pointer in reducing program codes
CO5	Demonstrate dynamic memory allocation on the basis of using basic test operator

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA01005 DATA STRUCTURE LAB 2 Credits [0-0-3]

The candidates should be able to handle with windows and do the following programme by a computer in C:

1. Application of Euclidian algorithm to find gcd of two numbers.
2. Generation of Fibonacci sequence using recursion and find the number that are perfect square.
3. Generate a list of primes between 1 and n. Find the twin primes.
4. Write a program to find all factors of a number.
5. Construct a magic square of dimension n x n (n is odd)
6. Draw Pascal's triangle.
7. Find the average value of n numbers.
8. Write a program to multiply two numbers having more than 5 digits each.
9. Determination of roots byNewton Raphson Method.
10. Interpolations by Newtonian method.
11. Numerical Integration bySimpson's 1/3 Rule.
12. Numerical solution of differential equation byEuler method.
13. Matrix inversion by Gauss elimination method.
14. Summation of series

    a) $\sum 1/n! = e$ b) Sine series c) Cosine series
15. Data Handling.

    Sorting: Bubble sort

    Searching: Linear search

Course Outcomes:

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

CO1	Demonstrate a working knowledge of mathematical applications in a variety of applied fields
CO2	Demonstrate basic mastery data handling
CO3	Perform the tracing of curves
CO4	Perform the summation of series.
CO5	Demonstrate numerical methods with error estimation

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	2	3	3	3	2
CO2	3	2	3	3	3	2
CO3	3	2	3	3	3	2
CO4	3	2	3	3	3	2
CO5	3	2	3	3	3	2

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	2	3	3	3	2

MMA02001 MEASURE THEORY AND INTEGRATION 4 Credits [3-1-0]

Module–I

Sigma algebra of sets, Borel sets of R, Lebesgue outer measure and its properties, Sigma algebra of measurable sets in R, non-measurable sets, measurable sets which is not a Borel set, Lebesgue measure and its properties, Cantor set and its properties, measurable functions, simple function.

Module–II

Integration of nonnegative functions, Riemann and Lebesqueintegration, monotone convergence theorem, Fatou'slemma, and dominated convergence theorem, differentiation, function of bounded variation, Lebesquedifferentiation theorem.

Module–III

Abstract measure space, L^p-spaces, Holder and Minkoskiinequality, Completeness of L^p.

Module-IV

Modes of convergence, point wise convergence and convergence in measure, convergence diagrams and counter examples, Egorov's theorem,

Module- V

Complex and signed measure, Hahn decompositions, Jordan decomposition, Radon-Nikodym theorem(Statement Only), product measure, Fubinitheorem.

Reference Books:

1. Measure Theory and Integration, G. De Barra. (New age International)
2. Real Analysis, H.L. Royden (Pentice Hall of India)
3. Real and Complex Analysis, W. Rudin (Tata McGraw Hill of India)
4. Measure Theory & Integration, I.K. Rana. (New Age Publication)

Course Outcomes:

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

CO1	Recognize basic knowledge of measurable sets and its consequences
CO2	Apply the knowledge of measurable functions and its application to Lebesgue integration and differentiation
CO3	Describe measure space and its completion
CO4	Analyze types of convergence in measurable spaces
CO5	Demonstrate working knowledge on signed measure, product measure and its application

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA02002 COMPLEX ANALYSIS 4 Credits [3-1-0]

Module–I

Complex Field, complex plane, polar representation of complex numbers, lines and half planes, the extended plane and its spherical representation, more on analytic functions, Cauchy Riemann equations, Laplace's equation, Harmonic functions.

Module–II

Exponential, logarithmic, trigonometric and hypergeometric functions, conformal mapping, bilinear transformation, fixed points, Mobius transformation, Cross-ratio.

Module–III

Riemann-stieltjes integral, power series representation of analytic functions, the index of a closed curve, Cauchy theorem.

Module–IV

Cauchy's integral formula, Liouville's theorem, fundamental theorem of algebra, Morera's theorem, Goursat theorem.

Module–V

Zeros, poles, classification of singularities, Taylor and Laurent series, residues, argumentprinciple, Rouche's theorem, maximum modulus theorem, Schwarz's lemma.

Reference Books:

1. J. B. Conway, Functions of one Complex Variable, Norosa.
2. S. Ponnusamy, Foundation of Complex Analysis,Norosa.
3. L.V. Ahlfors, Complex Analysis, Mc Graw-Hill.

Course Outcomes:

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

CO1	Define field structure and deficiency of complex number system, and analyze analyticity
CO2	Realize mappings and their properties in 2D-plane in connection to complex plane
CO3	Describe advantage of Laurent series over Taylor series and technical aspect of Cauchy theorem
CO4	Demonstrate the fundamentals of connectedness in complex integration
CO5	Apply residues to solve improper integrals in potential theory, apply residue integration method to solve modeling problems

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA02003 TOPOLOGY 4 Credits [3-1-0]

Module–I
Basic concepts of topology, examples, bases, subbases, closed sets, limit points, continuous functions.
Module–II
New topologies from old: Subspace topology, order topology, product topology, metric topology.
Module–III
Connectedness, local connectedness, path-connectedness, countability and separation axioms.
Module-IV
Compact Spaces, compactness in metric spaces, locally compacts spaces, limit point compactness.
Module-V
T1, T2 – axioms, regular and completely regular space, normal spaces, Uryshon Lemma.

Reference Books:

1. J.R. Munkres, A First Course in Topology, Pearson.
2. J.L.Kelley, General Topology, Springer.

Course Outcomes:
Upon completion of the course, the students will be able to:

CO1	Define concept of basis and sub-basis of a topology
CO2	Demonstrate different types of topology
CO3	Describe connected topological spaces
CO4	Demonstrate compact topological spaces
CO5	Organize higher topological spaces

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA02004 NUMERICAL ANALYSIS 4 Credits [3-1-0]

Module–I

Numerical solutions of algebraic and transcendental equations: Iteration methods based on first degree equations (Secant, Regula-Falsi and Newton Raphson methods), Iteration methods based on second degree equation (Muller and Chebyshev methods), Rate of convergence.

Module–II

Interpolations: Lagrange and Newton interpolations, Finite difference operators, interpolating polynomials using finite differences, Hermite interpolation, error of polynomial interpolations, piecewise and spline interpolation (basic idea).

Module–III

Integration: Trapezoidal and Simpson's rules, Methods based on interpolation, Methods based on undetermined coefficients (Gauss-Legendre, Gauss-Chebyshev, Gauss-Laguerre, Gauss-Hermite, Lobatto and Radau), Composite integration methods.

Module–IV

Numerical Solution of system of linear equations:Gauss elimination, LU decomposition, Gauss-Jordan Elimination method, Triangularization method, Cholesky method, Iteration methods (Jacobi, Gauss-Seidel).

Module–V

Numerical solution of ordinary differential equation: Euler Method, Backward Euler method, Mid-point method, Single Step methods (Tayler series method, 2^{nd} and 4^{th}-order Range-Kutta method).

Reference Books:

1. M.K. Jain, S.R.K. Iyengar, R.K. Jain: Numerical methods for scientific and engineering computation, New Age International Ltd., New Delhi.
2. K. Atkinson: Elementary Numerical Analysis, Wiley, New York.

Course Outcomes:

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

CO1	Describe various numerical techniques to find the root of nonlinear equations
CO2	Implement various interpolation techniques for approximating functions
CO3	Incorporate with various techniques to evaluate numerical integrations
CO4	Demonstrate numerical solutions of system of linear equations
CO5	Compute solutions of ordinary differential equations using various numerical methods

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA02005 Numerical Methods using MATLAB 2 Credits [0-0-3]

Write a MATLAB program to:

1. fit a straight line of the form y = a x + b, for a given data, using the method of least square.
2. find the smallest positive root using fixed point iteration method.
3. find the smallest positive root using Newton- Raphson method.
4. find the solution of the system of linear equations using Gauss Seidel Method.
5. interpolate y using the given pair of values of x and y by Lagrange's interpolation.
6. find the derivative at the initial point using Newton 's Forward Difference Method.
7. find the derivative at the final point using Newton 's Backward Difference Method.
8. integrate Numerically using Trapezoidal & Simpson's Rule.
9. integrate Numerically using Gauss Quadrature Rule.
10. solve the Differential Equation $\frac{dy}{dx} = f(x, y),\ y(x_0) = y_0$ at the specified pivotal points by using the Runge-Kutta Method of 2^{nd} and 4^{th} order.

Course Outcomes:

Upon completion of the course, the students will demonstrate the ability to:

CO1	Apply MATLAB code for fitting straight line
CO2	Implement MATLAB code for the solutions of nonlinear equations
CO3	Perform numerical integration and differentiation by MATLAB
CO4	Compute solutions of ordinary differential equations using MATLAB
CO5	Estimate errors obtained out of numerical computations

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	3	2
CO2	3	1	3	3	3	2
CO3	3	1	3	3	3	2
CO4	3	1	3	3	3	2
CO5	3	1	3	3	3	2

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	3	2

THIRD SEMESTER

MMA03001 FUNCTIONAL ANALYSIS 4 Credits [3-1-0]

Module–I

Metric spaces, Normed linear spaces, inner product spaces, examples.

Module-II

Completeness of metric spaces, Banach spaces, L^p-spaces, Hilbert spaces.

Module-III

Orthonormality, Gram-Schist orthonormalizations, Bessel's inequality, Riesz-Fisher theorem, Fourierexpansion, Parseval's formula, Rieszrepresentation theorem.

Module-IV

Hahn Banach Theorem, Baire's category theorem, Open mapping Theorem, Closed graph theorem, uniform boundedness principle, duals of L^p and C [a,b].

Module–V

Bounded Linear operators: Definition and examples, spectrum of a bounded operator, resolventset.

Reference Books:

1. Kreyszig, Functional Analysis, John Wiley.
2. Limaye, Functional Analysis, Narosa.
3. Goffman & Pedrick, A first Course in Functional Analysis, Wiley Eastern
4. Bachman &Narici, Functional Analysis.

Course Outcomes:

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

CO1	Describe idea about advanced vector spaces like metric, normed and inner product space
CO2	Demonstrate Banach spaces, L^p-spaces and Hilbert spaces
CO3	Implement elementary applications of metric, normed and inner product spaces
CO4	Analyze advanced applications of Banach spaces, Hilbert spaces and inner product spaces.
CO5	Recognize various operators

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMA03002 ABSTRACT ALGEBRA 4 Credits [3-1-0]

Module-I

Normal subgroups: Normal subgroups and quotient groups, isomorphism theorems, automorphisms Permutation groups: Cyclic decomposition, symmetric groups.

Module-I

Structure theorems of groups: Direct products, finitely generated abelian groups, Invariants of a finite abelian group, Sylow theorems and their applications.

Module-III

Rings, homomorphisms, ideals, prime and maximal ideals, quotient rings, unique factorization domains, Principle ideal domains, Euclidean domains

Module-IV

Polynomial rings and irreducibility criteria, Polynomial rings over UFD, Nilpotent and nil ideals, Zorn's lemma.

Module-V

Fields, finite fields, field extensions, Galois theory.

Reference Books:

1. D.S. Dummit and R.M. Foote: Abstract Algebra, Wiley.
2. I.N. Herstein: Topics in Algebra, Wiley Eastern Ltd.
3. P.B. Bhattacharya, S.K. Jain and S.R. Nagpaul: Basic Abstract Algebra, 2nd edition, Cambridge University Press.
4. Contemporary Abstract Algebra, G. Gallian, Narosa

Course Outcomes:

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

CO1	Describe the concept of normal subgroups, quotient groups and apply the isomorphism theorems in various problems
CO2	Demonstrate knowledge and understanding of permutation groups and their properties
CO3	Analyze the structure of rings and associate properties
CO4	Define polynomial rings and irreducibility criteria
CO5	Demonstrate knowledge of field and its extension

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

List of Elective (Elective-I) Courses for 3rd Semester

MMAPE301 STATISTICAL METHOD 4 Credits [3-1-0]

Module-I

Axiomatic probability, independent events, addition rule, Bayes' rule, random variable, expectations, moment generating functions, characteristic functions, its properties, statement of inversion theorem.

Module–II

Moment generating functions, characteristic functions, its properties, derivation of characteristic function for a given distribution function, basic discrete distributions and their properties. Bernoulli, Binomial, Poisson, negative Binomial, geometric, hypergeometric and uniform distributions.

Module–III

Their characteristic function and moment generating functions of continuous distributions: Rectangular, Gamma, Beta, Normal, Cauchy, Exponential, Lognormal distributions and their properties

Module–IV

Stochastic Process:Introduction, classification, Bernoulli process, poisson process, renewal process, availability analysis, random incidence, renewal model of program behavior

Module–V

Discrete Parameter Markov Chains: Introduction, computation of n-step transition probabilities, state classification and limiting distribution.

Reference Books:

1. Probability Distribution Theory and Statistical Inference, K. C. Bhuyan, New Central Book Agency Pvt.Ltd.
2. Probability& Statistics with Reliability, Queuing, and Computer Science Application. Kishor S. Trivedi, PHI Learning Pvt.Ltd.,
3. Fundamental of Mathematical Statistics, S.C. Gupta and V.K. Kapoor

Course Outcomes:

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

CO1	Define MGF in find various order moment of random variable
CO2	Develop knowledge of the properties of random occurrence, characteristic function
CO3	Produce characteristic function of different continuous distribution
CO4	Analyze probability and statistical inferences to draw conclusions
CO5	Apply the knowledge of probabilistic method to understand Markov process.

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE302 MATHEMATICAL MODELLING 4 Credits [3-1-0]

Module–I

Techniques, classification and characteristics of mathematical models, mathematical modellng through geometry, algebra, calculus, limitation of mathematical modelling.

Module–II

Mathematical modelling through differential equation, linear growth and decay model, compartment model, modeling of geometrical problems.

Module–III

Mathematical modeling modelling on population dynamics, mathematical modelling of epidemics through system of ode of first order, compartment models through system of ODEs.

Module–IV

Mathematical modelling in economics, medicine, arms race, battles and in duration al trades through system of ode of first order.

Module–V

Mathematical modeling of planetary motion, circular motion, motion of satellite through linear differential equation of second order.

Reference Books:

1. J. N. Kapur, Mathematical Modelling, Wiley Eastern Ltd. 1990
2. D. N. Burghes, Modelling through Differential Equations, Ellis Horwood& John Wiley.
3. C. Dyson & E. Levery, Principle of Mathematical Modelling, Academic Press New York.
4. F. R. Giordano& M.D. Weir, First Course in Mathematical Modelling, Books Cole California.

Course Outcomes:

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

CO1	Describe basic modelling through 1^{st} order ODEs
CO2	Develop the knowledge of modelling of geometrical problems
CO3	Incorporate the validity with concepts of simulation and modelling
CO4	Apply the modelling in economics, medicine, arms race and battles
CO5	Demonstrate modelling of circular motion and motion of satellite

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE303 PARTIAL DIFFERENTIAL EQUATION 4 Credits [3-1-0]

Module–I

Classification of first order Partial differential equations, Semi-linear and quasi-linear equations, Lagrange's method, Compatible systems, Charpit's method, Jacobi's method.

Module–II

Integral surfaces passing through a given curve, Cauchy problem, method of characteristics for quasi-linear and non-linear partial differential equation.

Module–III

Linear Second order partial differential equations: Second order linear equations in two variables and their classification; one dimensional wave equation, vibration of an infinite string,D'Alembert's solution, vibrations of a semi finite string, vibrations of a string of finite length.

Module–IV

Laplace equation, Boundary value problems, Maximum and minimum principles, Dirichilet problem for a circle, Dirichlet problem for a circular annulus, Neumann problem for a circle.

Module–V

Heat equation, Heat conduction problem for an infinite rod, Heat conduction in a finite rod, existence and uniqueness of the solution, classification in higher dimension.

Reference Books:

1. Phoolan Prasad and RenukaRavindran, Partial Differential Equations, Wiley Eastern Ltd.
2. F. John, Partial Differential Equations, Springer-Verlag, New York.
3. Tyn-Myint-U, Partial Differential Equations, North Holland Publication, New York.
4. T. Amarnath, An elementary course in partial differential equation, Narosa.

Course Outcomes:

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

CO1	Recognize fundamental knowledge of partial differential equation
CO2	Develop the integral surfaces passing through a given curve
CO3	Apply different techniques to solve second order partial differential equations
CO4	Demonstrate the working knowledge of boundary value problems
CO5	Apply the theory PDEs in heat equation

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE304 OPERATOR THEORY 4 Credits [3-1-0]

Module–I

Banach Algebra, Introduction, Complex homomorphism Basic properties of spectra, Commutative Banach Algebra: Ideals, Gelfand transform, Involution, Bounded operator.

Module–II

Bounded Operator, Invertibility of bounded operator, Adjoints, Spectrum of bounded operatoer, Fundamentals of spectral Theory, Self adjoint operators, Normal, Unitary operators, Projection Operator.

Module–III

Resolution of the Identity, Spectral Theorem, Eigen Values of Normal Operators, Positive Operators, Square root of Positive operators, Partial Isometry, Invariant of Spaces, Compact and Fredholm Operators, Integral Operators.

Module–IV

Unbounded Operators, Introduction, Closed Operators, Graphs and Symmetric Operators, Cayley transform, Deficiency Indices, Resolution of Identity.

Module-V

Spectral Theory,Spectral Theorem of normal Operators, Semi group of Operators.

Reference Books:

1. Walter Rudin, Functional Analysis, Tata McGraw Hill.
2. Gohberg and Goldberg, Basic Operator Theory.
3. M. Schecter, Principle of Functional Analysis
4. Akhietzer and Glazeman, Theory of Linear Operator, Vol. I, II, Pitman Publishing House.
5. Donford and Schwarz, Linear Operator, vol. 1. 2. 3.
6. Weidman j., Linear Operators on Hilbert Spaces, Springer.

Course Outcomes:

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

CO1	Describe Commutative Banach algebra and operators on them
CO2	Organize the knowledge about advanced operators
CO3	Perform Eigen value analysis of operators
CO4	Describe about closed and unbounded operators
CO5	Demonstrate spectrum of normal operators

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE305 ANALYTIC NUMBER THEORY 4 Credits [3-1-0]

Module–I

Divisibility, Greatest common divisor, Prime numbers, Fundamental Theorem of arithmetic, Euclidean algorithm Arithmetical functions and Dirichlet Multiplication: Mobius function, Euler totient function, Dirichlet product of arithmetical functions, Dirichlet inverses and the Mobius inversion formula, Mangoldt function, Multiplicative functions and Dirichlet multiplication, Liouville's function, Divisor functions

Module–II

Average of arithmetical functions: Asymptotic equality of functions, Euler's summation formula, average order of d(n), the divisor functions, phi(n), mu(n) and $\Lambda(n)$, partial sums of a Dirichlet product
Elementary theorems on distribution of primes numbers: Chebyshev'sfunctions,equivalent forms of prime number theorem, inequalities for pi(n) and p_n, Shapiro's Tauberian theorem

Module–III

Congruences: Definition and basic properties, residue classes, complete residue systems, Linear congruences, reduced residue systems and the Euler-Fermat theorem, Polynomial congruences modulo p, Lagrange's theorem and its applications, Simultaneous linear congruences, Chinese remainder theorem and its applications

Module–IV

Periodic arithmetical functions and Gauss sums: Functions periodic modulo k, existence of finite Fourier series for periodic arithmetical functions, Ramanujan's sum and generalizations and its multiplicative properties.
Quadratic residues and Quadratic Reciprocity law: Quadratic residues, Legendre's symbol and its properties, Gauss lemma, quadratic reciprocity law and its applications, Jacobi symbol.

Module–V

Dirichlet Series and Euler products: Half-plane of absolute convergence of a Dirichlet series, function defined by a Dirichlet series, Multiplication of Dirichlet series, Euler products, Analytic properties of Dirichlet series.
Zeta functions: Introduction, properties of gamma function, Integral representation and contour integral representation for the Hurwitz zeta function, analytic continuation of Hurwitz zeta function

Reference Books:

1. Tom. M. Apostol, An Introduction to Analytic Number Theory.
2. Chandra Shekharan K., Introduction to Analytic Number Theory.
3. G.H. Hardy & E.W. Wright., Theory of Numbers.
4. I. Niven & H.S. Zukerman, An Introduction to Theory of Numbers

Course Outcomes:

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

CO1	Apply fundamental theorem of arithmetic and identify various arithmetical functions
CO2	Demonstrate the distribution of prime numbers
CO3	Analyze the knowledge of theory of congruences and solve system of linear congruences
CO4	Recognize brief idea about quadratic residues and quadratic non-residues and its application to Diophantine equations
CO5	Demonstrate theory of zeta- and L-functions

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

List of Open Elective Courses for 3rd Semester

MMAOE301 DISCRETE MATHEMATICAL STRUCTURES 4 Credits [3-1-0]

Module–I

Counting: Permutation combination and discrete probability, computability and formal language, Russell's paradox, ordered sets.

Module-*II*

Relation: Binary relation and properties, matric representation, closure of relation, Warshals algorithm

Recurrence relation: Homogeneous and nonhomogeneous, generating functions.

Module–III

Graphs: Basic terminology, Multi graph and weighted graphs, Paths and circuits, Eulerian Paths and circuits, Hamiltonian paths and circuits,

Module–IV

Trees: Rooted trees, binary search trees, spanning trees, minimal spanning tree, cut sets

Module–V

Lattices and algebraic systems, principle of duality, basic properties of algebraic systems defined by lattices, distributive and complemented lattices

Boolean algebras, uniqueness of finite Boolean algebras, Boolean function and Boolean expressions. *K*-map.

Reference Books:

1. C.L Liu, Elements of Discrete Mathematics (second edition), Tata McGraw Hill edition
2. K.H. Rosen: Discrete Mathematics and its application, 5th edition, Tata McGraw Hill.

Course Outcomes:

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

CO1	Apply counting principle
CO2	Incorporate the knowledge of relation and recurrence relation
CO3	Describe basic idea of graph and applications
CO4	Design trees and spanning trees
CO5	Demonstrate application of Boolean lattices and Boolean algebras

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAOE302 MATRIX ALGEBRA 4 Credits [3-1-0]

Module-I
Matrix multiplication, systems of linear equations, triangular systems, positive definite systems; Cholesky decomposition, Banded positive definite systems, sparse positive definite systems, Gaussian elimination and the LU decomposition, Gaussian elimination with pivoting, sparse Gaussian elimination.

Module-II
Sensitivity of Linear Systems: Vector and matrix norms, condition numbers.
The least squares problem, the discrete least squares problem, orthogonal matrices, rotators, and reflectors, solution of the least squares problem.

Module-III
The Gram-Schmidt process, geometric approach, updating the QR decomposition. Singular value decomposition, introduction, some basic applications of singular values.

Module-IV
Systems of differential equations, basic facts, the power method and some simple extensions, similarity transforms, reduction to Hessenberg and tridiagonal forms, QR algorithm, implementation of the QR algorithm, use of the QR algorithm to calculate eigenvectors, SVD revisited.

Module-V
Eigen values and eigen vectors, eigen spaces and invariant subspaces, subspace iteration, simultaneous iteration, and the QR algorithm, eigen values of large, sparse matrices, eigen values of large, sparse matrices, sensitivity of eigen values and eigenvectors, methods for the symmetric eigenvalue problem, the generalized eigenvalue problem.

Reference Books:

1. Fundamentals of Matrix Computation by David S Watkins, Wiley
2. Matrix Computations by Gene H. Golub, Charles F.Van Loan The Johns Hopkins University Press, Baltimore.
3. Text book of Matrix Algebra by S. K. Paikray, Kalyani Publisher

Course Outcomes:

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

CO1	Organize various systems of linear equations and implement matrix theory to solve them
CO2	Develop discrete least square problem and find its solution
CO3	Demonstrate working knowledge of singular value decomposition and its applications
CO4	Compile systems of differential equations using various methods
CO5	Describe eigenvalues and eigenvectors of matrices and perform its sensitivity analysis

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAOE303 GRAPH THEORY 4 Credits [3-1-0]

Module-I

Basic Terminologies, connectedness, walk, path circuits, Eulerian graph, Hamiltnian graph, some applications.

Module-II

Planarity: Kuratowski's two graphs, detection of planarity, Euler's formula, geometric dual

Module-III

Graph coloring: coloring of some standard graphs, chromatic number, map coloring, four color problem. Chromatic polynomial

Module-IV

Trees: Elementary properties of trees, rooted tree, binary tree, spanning tree, Kruskal's and Prim's algorithmmore applications. cut sets: fundamental circuits and cut-sets

Module-V

Directed graph: digraphs and binary relations, adjacency and incidence matrices, strongly connectedness, Euler digraphs.

Reference Books:

1. R. J. Wilson, Introduction to Graph Theory, Longman.
2. N. Deo Graph Theory and its Application to Engineering and Computer Science.
3. F. Harary, Graph Theory, Addison Wesley.

Course Outcomes:

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

CO1	Describe Basic Terminologies and connectedness in graph theory
CO2	Analyze detection of planarity and Euler's formula
CO3	Demonstrate graph coloring and chromatic number
CO4	Recognize elementary properties of trees, rooted tree, binary trees and spanning trees MST algorithm
CO5	Describe directed graph and adjacency matrices, and analyze strongly connectedness of digraphs

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

FORTH SEMESTER

MMA04001 OPERATIONS RESEARCH 4 Credits [3-1-0]

Module–I

Post-Optimal Analysis: Changes in objective function coefficients, changes in the b_i values, changes in the coefficients a_{ij}'s, structural changes, applications of post-optimal analysis.

Module–II

Integer Programming: Pure and mixed IPP, Gomory's all-IPP method, construction of Gomory's constraints, fractional cut method- all integer IPP & mixed integer IPP, Branch and Bound Method. Introduction to dynamic Programming, solution of LPP by DP techniques

Module–III

Theory of Games: Two person zero sum games, maxmin and minmax principle, graphical solution of 2 x n and n x 2 games, dominance rule, general solution of rectangular games by LP method.

Sequencing Problem: Problem of sequencing, processing n jobs through two machines, processing n jobs through k machines, processing 2 jobs through k machines, maintenance crew scheduling.

Module–IV

Non-linear Programming: General non-linear programming problem (NLPP), constrained optimization with equality constraints, constrained optimization with inequality constraints, Kuhn Tucker conditions with non-negative constraints.

Module–V

Non-linear Programming: Quadratic Programming, Wolfe's modified simplex method, Beale's method.

Reference Books:

1. Kanti Swarup et al, Operations Research, 18^{th} Edition, Sultan Chand & Sons.
2. J. C. Pant, Introduction to Optimization and Operations Research. Jain Brothers, New Delhi.

Course Outcomes:

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

CO1	Analyze the effect on optimal solutions of LPPs on changing various
CO2	Apply integer and dynamic programming problems in appropriate areas
CO3	Demonstrate game theory and sequencing problems
CO4	Recognize the idea of nonlinear programming problems and use of KKT conditions
CO5	Demonstrate knowledge of various methods to solve Quadratic programming problems

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

List of Elective Courses (Elective-II & III) For 4th Semester

MMAPE401 CRYPTOGRAPHY 4 Credits [3-1-0]

Module–I

Classical cryptosystems, Preview from number theory, Congruences and residue class rings, DES-security and generalizations, Prime number generation. Public Key Cryptosystems of RSA, Rabin, etc. their security and cryptanalysis.

Module -II

Primality, factorization and quadratic sieve, efficiency of other factoring algorithms. Finite fields: Construction and examples. Diffie-Hellman key exchange. Discrete logarithm problem in general and on finite fields. Cryptosystems based on Discrete logarithm problem such as Massey- Omura cryptosystems.

Module -III

Algorithms for finding discrete logarithms, their analysis. Polynomials on finite fields and Their factorization/ irreducibility and their application to coding theory. Elliptic curves, Public key cryptosystems particularly on Elliptic curves.

Module-IV

Problems of key exchange, discrete logarithms and the elliptic curve logarithm problem. Implementation of elliptic curve cryptosystems. Counting of points on Elliptic Curves over Galois Fields of order 2m. Other systems such as Hyper Elliptic Curves and cryptosystems based on them.

Module-V

Combinatorial group theory: investigation of groups on computers, finitely presented groups, coset enumeration. Fundamental problems of combinatorial group theory. Coset enumeration, Nielsen and Tietze transformations. Braid Group cryptography.

Cryptographic hash functions. Authentication, Digital Signatures, Identification, certification infrastructure and other applied aspects.

Reference Books:

1. Douglas R. Stinson, Cryptography: Theory and Practice, Chapman and Hall.
2. Serge Vaudenay,A Classical Introduction to Cryptography.
3. Johannes A. Buchmann,Introduction to Cryptography.

Course Outcomes:

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

CO1	Describe elementary number theory and classical cryptosystems
CO2	Describe the concepts of Discrete logarithm problem and its use in cyrptosystems
CO3	Demonstrate the irreducibility of polynomials on finite fields, get the idea of elliptic curves and its use in public key cryptosystems
CO4	Recognize the of elliptic curve cryptosystems and develop hyper elliptic curves
CO5	Describe the fundamentals of combinatorial group theory and cryptographic hash functions

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE402 VECTOR OPTIMIZATION 4 Credits [3-1-0]

Module-I

Linear Spaces: Introduction; Vector Spaces: Definitions and Examples, Subspaces, Linear Combinations and Varieties, Linear Independence, Dimension, Convexity and Cones: Convex Cone, Positive Cone, Positive Dual Cone

Module-II

Normed Linear Spaces: Definitions and Examples, Open and Closed Sets, Convergence, Transformations and Continuity, Banach Spaces, Quotient Spaces
Dual Spaces: Introduction, Basic Concepts, Duals of Some Common Banach Spaces, Extension of Linear Functionals, Second Dual Space

Module-III

Optimization of Functionals: Frechet and Gateaux Derivatives, Higher
Order Frechet Derivatives, Euler Lagrange Equations, Convex and Concave Functionals and its Conjugate, Dual Optimization Problems

Module-IV

Constraint Optimization: Introduction, Positive Cones and Convex Mappings, Lagrange Multipliers, Sufficiency, Sensitivity, Duality; Lagrange Multiplier Theorems, Optimal Control Theory.

Module-V

Solution of Constrained Problems: Projection Method, Primal-Dual Method, Penalty Functions

Reference Books:

1. D. G. Luenberger, Optimization by Vector Space Methods, John Wiley and sons, Inc.,New York, (1968).
2. D. Lokenath and P. Mikusinski, Introduction to Hilbert Spaces with Applications, Academic Press, Inc., (1990).

Course Outcomes:

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

CO1	Describe the geometric principle of linear vector space theory
CO2	Apply the knowledge of the algebraic properties of different spaces
CO3	Demonstrate the knowledge of the algebraic properties of different spaces
CO4	Analyze the existence of solutions of constrained optimization problems
CO5	Describe constrained optimization problems by several methods.

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE403 APPLIED FLUID DYNAMICS 4 Credits [3-1-0]

Module-I

Introduction to fluid flow: Viscous and inviscid fluids, Laminar and turbulent flows, Steady and unsteady flows, Rotational and irrotational flows

Module-II

Kinematics of fluids in motion: Lagrangian and Eulerian method of fluid motion, Equation of continuity by Euler method, Equation of motion of inviscid fluid, Euler's equation of motion in cylindrical coordinates

Module-III

Euler's equation of motion under impulsive forces, Reynold number, Froude number, Mach number, Prandtl number, Eckert number, Grashoff number, orthogonal curvilinear coordinates.

Module-IV

Dynamic similarity, Inspection analysis in incompressible viscous fluid flow, Reynolds principle of similarity, Inspection analysis in case of viscouscompressible fluid,

Module-V

Boundary layer theory: Limitation of ideal fluid, Prandtl's boundary layer theory, Boundary layer thickness, Boundary layer equation in two dimensional flow, Boundary layer flow over a flat plate (Blasius Solution).

Reference Books:

1. Fluid Dynamics, M.D. Raisinghania, 12^{th} Ed, S. Chand Co. Publisher
2. Viscous Fluid Dynamics, J.L. Bansal, Jaipur Publishing House
3. Foundations of Fluid Mechanics, S.W. Yuan, Prentice Hall of India Publisher

Course Outcomes:

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

CO1	Demonstrate a working knowledge of fluid flow
CO2	Analyze knowledge of Kinematics of fluids in motion
CO3	Apply Euler's equation of motion under impulsive forces
CO4	Express dynamic similarity and Reynolds principle of similarity
CO5	Describe Boundary layer theory

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE404 ADVANCED ABSTRACT ALGEBRA 4 Credits [3-1-0]

Module-I

Algebraic extensions of fields: Irreducible polynomials and Eisenstein criterion, adjunction of roots, algebraic extensions, algebraically closed fields.

Module-II

Normal and separable extensions: Splitting fields, normal extensions, multiple roots, finite fields, separable extensions.

Module-III

Galois Theory: Automorphism groups and fixed fields, fundamental theorem of galois theory, fundamental theorem of algebra.

Module-IV

Applications of Galois Theory to classical problems: Roots of unity and cyclotomic polynomials, cyclic extensions.

Module-V

Polynomials solvable by radicals, symmetric functions, ruler and compass constructions.

Reference Books:

1. P.B. Bhattacharya, S.K. Jain and S.R. Nagpaul: Basic Abstract Algebra, 2nd edition, Cambridge University Press. Chapters: 15,16,17,18.
2. I.N. Herstein: Topics in Algebra, Wiley Eastern Ltd.
3. D.S. Dummit and R.M. Foote: Abstract Algebra, Prentice Hall.

Course Outcomes:

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

CO1	Describe the irreducibility of a polynomial and implement the concepts of algebraic extension of fields, algebraically closed fields
CO2	Analyze finite fields, normal extension, separable extension
CO3	Demonstrate the fundamental theorem of algebra and fundamental theorem of Galois theory
CO4	Describe the properties of roots of unity and compute cyclotomic polynomials
CO5	Apply method of ruler and compass constructions

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE405 **WAVELET** **4 Credits [3-1-0]**

Module–I

Review of Fourier Analysis, Elementary ideas of signal processing, From Fourier Analysis to wavelet Analysis,

Module–II

Windowed Fourier Transforms: Time frequency localization, The reconstruction formulae.

Multiresolution analysis, Construction of Wavelets from MRA construction of compactly supported wavelets,

Module–III

Band limited Wavelets, Franklin wavelets on real line, Introduction to spline analysis, spline wavelets on real line, Orthonormal Wavelets, Examples.

Module-IV

Discrete transforms and algorithms, Discrete Fourier transform and the fast Fourier transform, Discrete cosine transform and the fast cosine transform,

Module-V

Decomposition and reconstruction algorithm for Wavelets, Wavelets and applications.

Reference Books:

1. Harnandez, E., A first Course in waveletes, CRC
2. Daubechies Ingrid, Ten Lectures on Wavetets.
3. Chui, An Intruduction to Wavetets, Academic Press.
4. Kaiser, G., A friendly guide to Wavelets, Bikhauser, 1994.
5. Kahane&LemaireRieusset Fourier series & Wavelets Gordon & Breach.

Course Outcomes:

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

CO1	Apply Fourier transform to signal processing
CO2	Analyze time-frequency localization
CO3	Demonstrate spline and orthonorml wavelets
CO4	Organize DFT and FFT
CO5	Apply wavelet to real life problems

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE406 **DATA SCIENCE** **4 Credits [3-1-0]**

Module- I

Data science terminology, process, roles of data scientist, types of data, data collection and management: sources of data, data collection APIs, data preparation, exploring and fixing data, data storage and management, using multiple data sources

Module- II

Hypothesis testing and classification, statistical inference, populations and samples, central tendencies, probability distributions, variance, distribution properties and arithmetic, fitting a distribution model, binary classification, logistic regression, ratio test, p- values and confidence intervals

Module- III

Non-statistical classifiers: Support vector machine, Naive Bayes classifier and perceptron classifier, model planning, model building

Module- IV

Data visualisation: Types of data visualisation, data for visualisation, data types, data encodings, retinal variables, mapping variables to encodings, visual encodings, plots and summaries

Module- V

Applications of Data Science, usecases in industry, recommenders and rankings, text and speech analysis, and natural language processing, technologies for visualisation, recent trends in various data collection and analysis techniques, various visualization techniques.

Text Books:

1. Cathy O'Neil and Rachel Schutt. *Doing Data Science, Straight Talk From The Frontline*. O'Reilly.
2. Trevor Hastie, Robert Tibshirani and Jerome Friedman. *Elements of Statistical Learning*, SecondEdition. 2009.

Reference Books:

1. Kevin P. Murphy. *Machine Learning: A Probabilistic Perspective*. 2013.
2. Avrim Blum, John Hopcroft and Ravindran Kannan. *Foundations of Data Science*.
3. G.James, D.Witten, T.Hastie,R.Tibshirani, *An introduction to statistical learning with applications in R*, Springer, 2013.

Course Outcomes:

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

CO1	Describe different type of data and their utility, and method of data collection
CO2	Analyze data on the basis of distribution after studying their behavior
CO3	Demonstrate the way and technique of non statistical classifier works
CO4	Recognize variable mapping on data sets and implement the connection of data set visualization in mapping
CO5	Apply data science in profit of health care, Poverty eradication, Industry

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE407 ADVANCED COMPLEX-ANALYSIS 4 Credits [3-1-0]

Module–I

Harmonic functions (Definition and basis properties), The mean-value Property, Poisson's formula.

Module–II

Functions with the mean-value Property, Harnack's Principle, Sub harmonic function, Weierstrass theorem, Partial fraction and factorization,

Module–III

The Riemann – Zeta function, The Gamma function, Entire functions (Jensen's formula, Hadamard's theorem).

Module–IV

Normal families, The Riemann-mapping theorem,

Module–V

Elliptic functions, Picard's theorem

Reference Books:

1. Lars, V. Ahlfors: Complex Analysis, Mc Graw Hill.
2. Conway, J.B.: Functions of one Complex Variables, Narosa.

Course Outcomes:

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

CO1	Demonstrate a working knowledge in use of Laplacian operator which further describe the role of harmonic function in potential theory
CO2	Apply partial fraction and factorization, Fundamental theorem of algebra
CO3	Describe Riemann – Zeta function and its properties
CO4	Incorporate working knowledge of Riemann-mapping theorem
CO5	Recognize Elliptic functions and Picard's theorem

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1

MMAPE408 MACHINE LEARNING 4 Credits [3-1-0]

Module-I

Introduction: Basic definitions, types of learning, hypothesis space and inductive bias, evaluation, cross-validation. Linear regression, Decision trees, over fitting

Module-II

Logistic Regression, Support Vector Machine, Kernel function and Kernel SVM, Density of Sequence of Integers, Warring Problem.

Module-III

Neural network: Perceptron, multilayer network, back propagation, introduction to deep neural network

Module-IV

Computational learning theory, PAC learning model, Sample complexity, VC Dimension.

Module-V

Ensemble learning. Clustering: k-means, adaptive hierarchical clustering, Gaussian mixture model

Reference Books:

1. Machine Learning. Tom Mitchell. First Edition, McGraw- Hill, 1997.
2. Introduction to Machine Learning Edition 2, by EthemAlpaydin S. Lang, Algebraic Number Theory

Course Outcomes:

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

CO1	Demonstrate the fundamental issues and challenges of machine learning: data, model selection, model complexity, etc.
CO2	Describe the strengths and weaknesses of many popular machine learning approaches
CO3	Recognize the underlying mathematical relationships within and across Machine Learning algorithms and the paradigms of supervised and un-supervised learning.
CO4	Apply Computational learning theory, PAC learning model, Sample complexity, VC dimension
CO5	Design and implement various machine learning algorithms in a range of real-world applications

Course Articulation Matrix

	PO1	PO2	PO3	PO4	PO5	PO6
CO1	3	1	3	3	2	1
CO2	3	1	3	3	2	1
CO3	3	1	3	3	2	1
CO4	3	1	3	3	2	1
CO5	3	1	3	3	2	1

1: Slight (Low) 2: Moderate (Medium) 3: Substantial (High) -: No Correlation

Program Articulation Matrix row for this Course

	PO1	PO2	PO3	PO4	PO5	PO6
Course	3	1	3	3	2	1