Revised Syllabus for Two Years Programme

in

M.Sc. in Engineering Mathematics

(2021-2022)

DEPARTMENT OF MATHEMATICS

INSTITUTE OF CHEMICAL TECHNOLOGY

(University Under Section-3 of UGC Act, 1956)

Elite Status and Center for Excellence

Government of Maharashtra

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A. Preamble:

Due to emergence of modern computing facilities, the applications of mathematics in all branches of engineering, medical sciences, and financial sectors have become extremely important. As a result, there has been an extraordinary demand for technically qualified persons having sound mathematical skills. However, most of the courses available in the country are devoted to either pure mathematics or some combination of pure and applied mathematics with a bit of computer programming knowledge.

The Master Program entitled “M.Sc. in Engineering Mathematics” is designed to create professionals who are equipped with practical knowledge of Mathematics, Statistics and Computer Programming. This is a two-year programme consisting of four semesters. The programme was started as a five-year project under UGC Innovative Schemes in 2011. The first revision of the syllabus took place in the academic year 2017-2018. This is second revision which will be implemented from the academic year 2021-2022.

The course is an optimal blend of mathematical theory and its applications. Subjects related to Applied Mathematics, Statistics and Machine Learning will train the students on the use of modern computational tools to solve real life problems which are relevant to industry and society. These applied courses are complemented by some foundation courses in pure mathematics. Students having gone through this course will have sound working knowledge with strong mathematical base which is necessary to address computational and statistical challenges encountered in the different areas of science and technology. During the course, students also work on a yearlong project under the supervision of faculty members of the department and most often the projects are carried out in collaboration with people from industry.

After completing this course students will have career opportunities both in industry and academia. Almost all the career paths open to graduates in Mathematics are also available to the students.

B. Regulations Related to the Degree of Master of Science in Mathematics (M. Sc. in Engineering Mathematics) Degree Course

- **Intake**

  20 candidates shall be admitted every year. The distribution of seats shall be as per the Institute’s norms.

- **Admission**
  a. Candidates who have taken the post-H.S.C. 3-year degree course of Bachelor of Science with 6 units of Mathematics at the third year of the course and any two of chemistry, physics, and statistics as the two other subjects at the first and second years of University of Mumbai or of any other recognized University; and passed the qualifying examination with at least 55% of the marks in aggregate or equivalent grade average. (50% for the backward class candidates only from Maharashtra State are eligible to apply).
  b. Candidates who have passed B.Sc. in Statistics or B.Tech./B.E. with at least four mathematics papers as part of the coursework from a UGC/AICTE recognized University/ Institute are also eligible for admission.
  c. The admissions will be done strictly based on merit; the marks obtained in entrance test conducted by ICT.
  d. The candidates who have cleared the qualifying examination in one sitting will be preferred.

- **Course structure**
  a. The course is a credit-based 4-semester (2-year) course.
  b. There will be two semesters in a year:
     i. Semester I and III (July to December)
     ii. Semester – II and IV (December to May)
     iii. Each semester will consist of 15-16 weeks of instructions including seminars / projects/assignments.
  c. At the end of each semester the candidates will be assessed as per the norms of the Institute.
  d. Semesters will be governed by academic calendar of the institute.

e. The requirement of attendance of the students shall be as per the norms of the Institute.
f. All the relevant academic regulations of the Institute shall be applicable to the course.
g. Assessment of the students will be done as per the norms of the Institute.
h. In case of any difficulty regarding any assessment component of the course, the Departmental Committee shall take appropriate decision, which will be considered final.

i. **Electives:**
   i. Three elective courses will be offered during the programme and the list of electives will be made available to the students.
   ii. Open electives will also be offered which may be of two types: (a) students can take it from well-established MOOC courses with prior approval from the department (b) it may be proposed by a faculty with detailed syllabus and get prior approval from the department.

j. **Project:**
   i. At the end of the Second semester, the Head of Department in consultation with the Departmental Committee will assign topics for seminar course to the students and assign the supervisors. Seminar course will create adequate background to the students for taking project in the fourth semester.
   ii. The students will do the project in semester IV on the topics assigned under the supervision of the assigned faculty member.
   iii. The students shall submit the project report before the prescribed date which will be a date before the last date of the semester IV. The report shall be submitted with soft binding.
   iv. The project report will be examined by the supervisor along with one other internal/external referee to be appointed by the Departmental committee. The referees shall give marks to the report as per the norms.
   v. The students will make presentation on the work in front of the Project Evaluation Committee (PEC) appointed by the Departmental Committee, in open defence form. The PEC will give marks to the presentation.
   vi. The comments received from the referees as well as given by the PEC need to be incorporated in the final project report in consultation with the supervisor.

Programme Outcomes (POs) for M.Sc. Engineering Mathematics

PO1	Fundamental knowledge of pure mathematics: Apply the fundamental concepts of pure mathematics to understand the concepts in Applied Mathematics, Statistics and Computational Mathematics and empowering students to engage in research and development in future into top industries and institutions.
PO2	Foundation of Applied Mathematics: Strong foundation of Applied Mathematics which is directly connected to solving real life problems in different domains by means of mathematical modelling and being able to apply them in solving complex problems relevant to the society and industry.
PO3	Foundation of Statistics and Data Science: Strong foundation of Mathematics and Statistics of Data science and good hold on various statistical methodologies including probability theory, estimation, and testing of hypothesis etc. and being able to apply them in solving real life problems.
PO4	Foundation of Machine Learning and AI: Understand and employ modern computational methods in Machine Learning including Deep Learning and Artificial Intelligence and use them effectively using free and proprietary advanced computational platforms for solving large scale problems arising from different research areas.
PO5	Research based Teaching Learning: An innovative teaching framework to engage students in both academic and industrial research and open up multiple future paths in different verticals including preparation to qualifying national level tests like NET/GATE etc and creation of future leaders in teaching.
PO6	Conduct investigations of complex problems: Use research-based knowledge in machine learning and artificial intelligence and research methods including design of experiments, analysis and interpretation of data to unfold complex problems from industry and academia and provide working solutions.
PO7	Problem analysis: Identify, formulate, review research literature, and analyze complex real life problems using mathematics, statistics, and computational methods.
PO8	Societal Applications of Mathematics: Apply reasoning informed by the existing knowledge pool to convert into a quantitative framework, collect relevant information and address various societal issues using modelling and statistical data analytics tools including deep learning and artificial intelligence.
PO9	Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the practice of mathematics, statistics and data sciences in all verticals of industry and society.
PO10	Individual and teamwork: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO11	Communication: Communicate effectively on complex industrial/natural problems and understand the functional requirements, identify the gaps and being able to provide solutions using modern tools and technologies offering advanced data sciences and machine learning techniques.
PO12	Life-long learning: Recognize the need for and have the preparation and ability to engage in independent and life-long learning, acquire appropriate skills in Mathematics and its application for the benefit of humankind.

M.Sc. in Engineering Mathematics
Institute of Chemical Technology, Mumbai

Semester-I									
Subject Code	**Subject**	**Credits**	**Hrs/Week**			**Marks for various Exams**			
			L	T	P	CA	MS	ES	Total
MAT 2201	Applied Linear Algebra	4	3	1	0	20	30	50	100
MAT 2202	Real Analysis-I	4	3	1	0	20	30	50	100
MAT 2221	Ordinary Differential Equation	4	3	1	0	20	30	50	100
MAT 2204	Modern Algebra	4	3	1	0	20	30	50	100
MAT 2321	Probability Theory	4	3	1	0	20	30	50	100
MAP 2521	Programming Lab	3	0	0	6	25		25	50
	Total	23	15	5	6				550

Semester-II									
Subject Code	**Subject**	**Credits**	**Hrs/Week**			**Marks for various Exams**			
			L	T	P	CA	MS	ES	Total
MAT 2205	Optimization Techniques	4	3	1	0	20	30	50	100
MAT 2207	Real Analysis II	4	3	1	0	20	30	50	100
MAT 2421	Numerical Methods	4	3	1	0	20	30	50	100
MAT 2322	Statistical Inference	4	3	1	0	20	30	50	100
MAT 2222	Partial Differential Equations	4	3	1	0	20	30	50	100
	Elective-I	4	3	1	0	20	30	50	100
	Total	24	18	6	0				600

Electives-I (SEM-II)									
Subject Code	Subject	Credits	Hrs/Week			Marks for various Exams			
			L	T	P	CA	MS	ES	Total
MAT 2601	Graph Theory	4	3	1	0	20	30	50	100
MAT 2602	Topology	4	3	1	0	20	30	50	100
MAT 2603	Number Theory	4	3	1	0	20	30	50	100
MAT 2604	Matrix Computations	4	3	1	0	20	30	50	100
	*Open Elective-I	4	3	1	0	20	30	50	100

***Open electives** may be of two types: (i) students can take it from MOOC (Swayam/NPTEL etc) course with prior approval from the department (ii) it may be proposed by a faculty with complete details of syllabus and get prior approval from the department.

Semester III									
Subject Code	Subject	Credits	Hrs/Week			Marks for various Exams			
			L	T	P	CA	MS	ES	Total
MAT 2210	Functional Analysis	4	3	1	0	20	30	50	100
MAT 2323	Statistical Computing	4	3	1	0	20	30	50	100
MAT 2324	Machine Learning	3	2	1	0	10	15	25	50
MAT 2206	Complex Analysis	4	3	1	0	20	30	50	100
	Elective-II	4	3	1	0	20	30	50	100
MAP 2701	Project Seminars	2	0	0	4				50
MAP 2522	Software Lab	2	0	0	4	25		25	50
	Total	23	14	5	8				550

Electives-II (SEM-III)									
Subject Code	Subject	Credits	Hrs/Week			Marks for various Exams			
			L	T	P	CA	MS	ES	Total
MAT 2621	Cryptography	4	3	1	0	20	30	50	100
MAT 2622	Finite Element Method	4	3	1	0	20	30	50	100
MAT 2623	Operation Research	4	3	1	0	20	30	50	100
MAT 2624	Mathematical Finance-I	4	3	1	0	20	30	50	100
MAT 2625	Multivariate Analysis	4	3	1	0	20	30	50	100
MAT 2626	Design and Analysis of Experiments	4	3	1	0	20	30	50	100
MAT 2627	Mathematical Biology	4	3	1	0	20	30	50	100
MAT 2628	Signal Processing	4	3	1	0	20	30	50	100
MAT 2629	Momentum, Heat and Mass Transfer	4	3	1	0	20	30	50	100
	*Open Elective -II	4	3	1	0	20	30	50	100

Semester-IV									
Subject Code	Subject	Credits	Hrs/Week			Marks for various Exams			
			L	T	P	CA	MS	ES	Total
MAT 2223	Combinatorics	4	3	1	0	20	30	50	100
MAT 2325	Deep Learning & Artificial Intelligence	3	2	1	0	10	15	25	50
MAT 2305	Stochastic Process	4	3	1	0	20	30	50	100
MAT 2402	Computational Fluid Dynamics	5	3	2	0	20	30	50	100
	Elective-III	4	3	1	0	20	30	50	100
MAP 2702	Project	4	0	0	8	50		50	100
	Total	24	14	6	8				550

Electives-III (SEM-IV)									
Subject Code	Subject	Credits	Hrs/Week			Marks for various Exams			
			L	T	P	CA	MS	ES	Total
MAT 2641	Dynamical Systems	4	3	1	0	20	30	50	100
MAT 2642	Integral Transforms	4	3	1	0	20	30	50	100
MAT 2643	Mathematical Finance-II	4	3	1	0	20	30	50	100
MAT 2644	Geometry of Curves and Surfaces	4	3	1	0	20	30	50	100
MAT 2645	Convex Optimization	4	3	1	0	20	30	50	100
MAT 2646	Time-Series Analysis	4	3	1	0	20	30	50	100
MAT 2647	Operator Theory	4	3	1	0	20	30	50	100
MAT 2648	Bayesian Statistics	4	3	1	0	20	30	50	100
	*Open-Elective-III	4	3	1	0	20	30	50	100

SEMESTER I

	Course Code: MAT 2201	Course Title: Applied Linear Algebra	Credits = 4		
			L	T	P
	Semester: I	Total contact hours: 60	3	1	0

List of Prerequisite Courses

Basics of matrix algebra and determinant of square matrix, vector spaces

List of Courses where this course will be prerequisite

It is a foundation course which will be prerequisite for all the course studied in this program

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This is a course further built up on and in continuation with undergraduate level course on linear algebra. This course reviews the major concepts of linear algebra and introduces advanced concepts with real life applications. Introduced concepts which will be used in almost all the later courses with special emphasis on Machine Learning and Deep Learning concepts.

	Course Contents (Topics and subtopics)	Hours
1	Review of Vector Spaces, Subspaces, Linear dependence and independence, Basis and dimensions.	6
2	Basic concepts in Linear Transformations; Use of elementary row operations to find coordinate of a vector, change of basis matrix, matrix of a linear transformations and subspaces associated with matrices.	8
3	Inner Product Spaces, Orthogonal Bases, Gram-Schmidt Orthogonalization, QR Factorization, Normed Linear Spaces.	12
4	Matrix Norm, condition numbers and applications.	4
5	Eigenvalue and Eigenvectors, Diagonalization and its applications to ODE, Dynamical Systems and Markov Chains, Positive Definite Matrices and their applications, Computation of Numerical Eigenvalues.	10
6	Singular Value Decomposition, Matrix Properties via SVD, Projections, Least Squares Problems, Application of SVD to Image Processing, Principal Component Analysis (PCA).	10
7	Structure of Linear Maps: Adjoint operators, Normal, Unitary, and Self-Adjoint operators, Spectral theorem for normal operators, Jordan Canonical Forms and its applications.	10

	List of Textbooks/ Reference books
1	S. Kumaresan, Linear Algebra – A Geometric Approach, Prentice Hall India.
2	David C Lay, Linear Algebra and its Applications, Addition-Wesley.
3	Richard Bronson and Gabriel B. Costa, Matrix Methods, Academic Press.
4	G. Strang, Linear Algebra and its Applications, Harcourt Brace Jovanish.
5	Robert Beezer, A First Course in Linear Algebra, open textbook (http://linear.ups.edu/html/fcla.html)
6	Carl D. Mayer, Matrix Analysis and Applied Linear Algebra, SIAM.
7	G. C. Cullen, Linear Algebra with Applications, Addison Wesley.

	Course Outcomes (students will be able to…..)
CO1	understand concepts in Linear Transformations and Inner Product spaces
CO2	understand basic concepts in Eigenvalues-Eigenvectors and Structure of Linear maps.
CO3	understand and work with various matrix factorization.
CO4	apply applied linear algebra concepts to solve real life problems.
CO5	apply concepts in eigenvalues-eigenvectors to solve real life problems.

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	5	4	5	3	1	1	0	5	1	0	5
CO2	5	5	4	5	0	1	1	0	5	1	0	5
CO3	5	5	5	5	0	1	1	1	5	1	0	5
CO4	4	5	5	5	4	5	4	1	5	3	4	5
CO5	4	5	5	5	4	5	4	4	5	3	4	5

	Course Code: MAT 2202	Course Title: Real Analysis – I	Credits = 4		
			L	T	P
	Semester: I	Total contact hours: 60	3	1	0

List of Prerequisite Courses		
Basic course in Calculus		
List of Courses where this course will be prerequisite		
Real Analysis – II (MAT 2207), Functional Analysis (MAT 2210)		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
It is a foundation course which is prerequisite for all the pure and applied mathematics topics including statistics in upcoming semesters		
	Course Contents (Topics and subtopics)	**Hours**
1	Sequences and series of functions, uniform convergence and its relation to continuity, differentiation, and integration. Fourier series, pointwise convergence, Fejer's theorem, Weierstrass approximation theorem	10
2	Functions of several variables, Level Sets, Convergence of sequences of several variables, Limits and continuity, Derivatives of scalar fields, Directional derivatives, Partial derivatives, Total derivative, Gradient of scalar fields, Tangent planes.	15
3	Derivatives of vector fields, curl, divergence, Chain rules for derivatives, Derivatives of functions defined implicitly, Higher order derivatives, Taylor's theorem and application, Inverse function theorem, Implicit function theorem, Local Maxima, Local Minima, Saddle points, Stationary points, Lagrange's multipliers.	20
4	Double and triple integrals, Iterated integrals, Change of variables formula, Applications of multiple integrals to area and volumes. Paths and line integrals, Fundamental theorems of calculus for line integrals, Line integrals of Vector fields, Green's theorem and its applications.	15
List of Textbooks / Reference books		
1	T. Apostol, Mathematical Analysis, 2nd Edition, Narosa, 2002.	
2	W. Rudin, Principles of Mathematical Analysis, 3rd Edition, McGraw-Hill	
3	Ajit Kumar and S. Kumaresan, A Basic Course in Real Analysis, CRC Press.	
4	T. M. Apostol, Calculus Vol. II, 2nd Ed., John Wiely& Sons.	
5	J. E. Marsden, A. Tromba, and A. Weinstein, Basic Multivariable Calculus, Springer-Verlag.	
6	Susane Jane Colly, Vector Calculus, 4th Edition, Pearson.	
Course Outcomes (students will be able to…..)		
CO1	understand the pointwise and uniform convergence of sequence and series of functions.	
CO2	understand the notion of differentiability from R^n to R^m.	
CO3	obtain Taylor series expansions of functions of several variables and compute maxima, minima and saddle points.	
CO4	learn about inverse and implicit function theorem and their applications.	
CO5	compute multiple integrals and line integrals.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	5	1	1	4	1	4	1	5	1	0	5
CO2	5	5	2	3	4	1	3	1	5	1	0	5
CO3	5	5	2	3	4	1	4	0	5	1	0	5
CO4	5	5	1	1	4	3	5	1	5	1	0	5
CO5	5	5	1	1	4	3	5	1	5	1	0	5

	Course Code: MAT 2221	Course Title: Ordinary Differential Equation	Credits = 4		
			L	T	P
	Semester: I	Total contact hours: 60	3	1	0

List of Prerequisite Courses

Basic course on Calculus and ordinary differential equations.

List of Courses where this course will be prerequisite

Partial differential equation (MAT 2222), Computational fluid dynamics (MAT 2402)

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

Ordinary differential equations are in the core of Applied Mathematics and this program emphasize on the applications of mathematics in different branches of science and engineering including industry.

	Course Contents (Topics and subtopics)	Hours
1	Review of first and second order ODE s Modelling differential equations.	4
2	Existence and Uniqueness theorems for first order ODEs.	4
3	Higher Order Linear Equations and linear Systems: fundamental solutions, Wronskian, variation of constants, matrix exponential solution, behaviour of solutions.	16
4	Power series method of solving ODE's and special functions	8
5	System of linear ODEs Two dimensional autonomous systems and Phase Space Analysis: critical points, proper and improper nodes, spiral points and saddle points. Asymptotic Behavior: stability (linearized stability and Lyapunov methods).	12
6	Boundary Value Problems for Second Order Equations: Green's function, Sturm comparison theorems and oscillations, eigenvalue problems.	10
7	Laplace Transforms and its application to solving IVP.	6

List of Textbooks/ Reference Books

1	William E. Boyce, Richard C. DiPrima, Elementary Differential Equation, Wiley
2	E. A. Coddington, An Introduction to Ordinary Differential Equations, PHI
3	G. F. Simons, S. G. Krantz, Differential Equation, Theory Techniques and Practice Tata McGraw-Hill
4	Zill, Dennis G, A First Course in Differential Equations, Cengage Learning
5	L.Perko, Differential Equations and Dynamical Systems, 2nd Ed., Springer Verlag.

Course Outcomes (students will be able to…..)

CO1	model differential equations from real world problems
CO2	solve higher order differential equations with constant coefficients.
CO3	solve differential equations with variable coefficients with power series method.
CO4	solve and find eigenvalues and eigenfunctions of Boundary value problems.
CO5	solve system of differential equations and analyse the solutions.

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	1	5	0	1	5	5	3	5	5	4	1	5
CO2	1	5	0	0	3	1	5	1	5	1	0	3
CO3	4	5	1	1	3	1	5	1	5	1	0	4
CO4	4	5	1	1	3	1	5	1	5	1	0	4
CO5	1	5	0	0	3	1	5	1	5	1	1	4

	Course Code: MAT 2204	Course Title: Modern Algebra	Credits = 4		
			L	T	P
	Semester: I	Total contact hours: 60	3	1	0

List of Prerequisite Courses

List of Courses where this course will be prerequisite

Combinatorics (MAT 2223)

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

It is a foundation course for pure mathematics having various applications in all branches of mathematics.

	Course Contents (Topics and subtopics)	Hours
1	Groups, subgroups, cosets, Lagrange Theorem, Normal subgroups, quotient groups. Focus on symmetric and alternating groups, Symmetry groups Dihedral groups as group of symmetries of a regular n-gon, Matrix groups.	10
2	Homomorphism theorems, Direct product of groups, Fundamental theorem for finite abelian groups (without proof).	8
3	Group actions, orbits and stabilizers, applications to the structure of groups, applications to combinatorics.	10
4	Rings, sub-rings and ideals, Integral domains and division rings. Focus on finite fields, polynomial and power series rings, roots and their multiplicities, matrix rings.	10
5	Prime and maximal ideals, Chinese remainder theorem, Euclidean domains, principal ideal domains and unique factorization domains, irreducibility of polynomials.	10
6	Extension fields, algebraic extensions, construction of finite fields, roots of polynomials and splitting fields, constructions with ruler and compass. Polynomial rings and matrix rings over finite fields.	12

List of Textbooks/ Reference Books

1	J. A. Gallian Contemporary Abstract Algebra, 4th Edition, Narosa.
2	Fraleigh J.B., A First Course in Abstract Algebra", 7th Ed. Pearson Education.
3	D. S. Dummit and R. M. Foote, Abstract Algebra, 2nd Edition, John Wiley.
4	M. Artin, Algebra, Prentice Hall of India.
5	G. Santhanam, Algebra, Narosa.

Course Outcomes (students will be able to…..)

CO1	understand basic concepts in groups, rings and fields.	
CO2	solve problems in basic group theory, rings and filed theory.	
CO3	apply notion of group action to classify groups of finite orders.	
CO4	prove fundamentals results and group theory, rings and filed theory.	
CO5	work with rings and fields over finite fields.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	4	3	0	4	3	2	1	5	1	0	5
CO2	5	1	0	0	4	1	4	1	5	1	0	4
CO3	5	1	0	0	4	1	3	1	5	1	0	4
CO4	5	1	0	0	4	3	2	1	5	1	0	5
CO5	5	1	0	1	5	4	4	1	5	1	0	3

	Course Code: MAT 2321	Course Title: Probability Theory	Credits = 4		
			L	T	P
	Semester: I	Total contact hours: 60	3	1	0

List of Prerequisite Courses

Basic course on Calculus

List of Courses where this course will be prerequisite

Statistical Inference (MAT 2322), Statistical Computing (MAT 2323), Machine Learning (MAT 2324), Deep Learning and Artificial Intelligence (MAT 2325), Stochastic Process (MAT 2305)

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This course is a foundation course covering major concepts of Probability theory. Introduced concepts which will be used in all statistics, machine learning and deep learning courses.

	Course Contents (Topics and subtopics)	Hours
1	Sets and operations, Sigma algebra, Probability Space, Combinatorics: Probability on Finite Sample Spaces, Conditional probability, and Bayes theorem	10
2	**Random Variables and Their Probability Distributions:** Random variables and Its distribution, Discrete and Continuous random variables, Functions of random variables and their distribution	8
3	**Moments and Generating Functions:** Moments of distribution function, generating functions (moment generating function, probability generating function, characteristic function, cumulant generating function, factorial moment generating functions) and their applications, Moment Inequalities	6
4	**Multiple Random Variables:** Joint distribution, Independence, functions of several random variables, Covariance, Correlation and joint moments, Conditional Expectation, Order Statistics and Their Distributions	10
5	**Some Special Distributions:** Common discrete distributions (Binomial, Poisson, Geometric, Negative Binomial, Discrete Uniform, Multinomial distribution), Common continuous distributions (Rectangular, gamma, Cauchy, Beta, Normal)	6
6	Bivariate and Multivariate normal distributions	4
7	**Sampling distribution:** Concept of Random sampling, Sample characteristics and their distribution, Chi-Square, *t*-, and *F*-Distributions: Exact Sampling Distributions; Sampling from Normal distribution	8
8	**Limit theorems:** Convergence concepts, Weak Law of Large Numbers and Strong Law of Large numbers, Central Limit Theorem, Elements of Large Sample Theory.	8

List of Textbooks / Reference Books

1	P.G. Hoel, S.C. Port and C.J. Stone, Introduction to Probability, Universal Book Stall, New Delhi.
2	K. Md. Ehsanes Saleh and V. K. Rohatgi. An Introduction to Probability and Statistics. Wiley.
3	G. Casella and R. L. Berger. Statistical Inference. Duxbury Press.
4	W. W. Hines, D. C. Montgomery, Probability and Statistics in Engineering. John Wiley.
5	V. Robert Hogg, T. Allen Craig. Introduction to Mathematical Statistics, McMillan Publication.
6	Vijay K. Rohatgi and A. K. Md. Ehsanes Saleh, An Introduction to Probability and Statistics, John Wiley & Sons, Inc.
7	A. M. Mood, F. A. Graybill and D. C. Boes, Introduction to The Theory of Statistics, Third Edition, Mc Graw Hill Education.
8	A. M. Gun, M. K. Gupta, B. Dasgupta, An Outline of Statistical Theory, Volume Two, World Press.

Course Outcomes (students will be able to…..)

CO1	apply axiomatic definition of probability to compute probability of events.	
CO2	obtain the distribution of functions of random variables.	
CO3	compute the moments and expectations of random variables.	
CO4	compute sampling distribution of the functions of random sample.	
CO5	apply convergence concepts to investigate large sample properties.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	1	2	5	5	4	4	5	4	5	1	1	5
CO2	1	2	5	5	1	3	5	3	5	1	0	5

CO3	1	2	5	5	1	3	5	3	5	1	0	5
CO4	1	1	5	5	3	4	5	3	5	0	0	5
CO5	4	3	5	5	4	5	5	4	5	3	1	5

	Course Code: MAP 2521	**Course Title: Programming Lab**	**Credits = 3**		
			L	**T**	**P**
	Semester: I	**Total contact hours: 60**	**0**	**0**	**6**
List of Prerequisite Courses					
List of Courses where this course will be prerequisite					
Software Lab (MAP 2522), Machine Learning (MAT 2324), Statistical Computing (MAT 2323), Deep Learning and Artificial Intelligence (MAT 2325)					
Description of relevance of this course in the M.Sc. Engineering Mathematics Program					
This M.Sc. program gives special emphasis on the implementation and application of large-scale computational techniques from applied mathematics and statistics. Hence, a good efficiency in mathematical programming is required in the upcoming semesters. Programming lab will give the students exposure to computational mathematics using latest software.					

Course Contents (Topics and subtopics)		**Hours**
Module-I (Python)		
1.	Introduction to Python Programming.	2
2	Python as an advanced scientific Calculator, use of math and cmath modules	2
3	Strings, List, tuples and dictionary data structures in Python	2
4	If and else controls and its applications	2
5	Creating user defined functions and creating Python modules	2
6	Loops in Python	4
7	Python Programmes to solve problems in numerical Analysis	4
8	Use of Numpy and Scipy	4
9	Plotting using Matplotlib	4
10	Classes in Python	4
11	Exploring data with Pandas	4
Module-II (R Programming)		
1	Introduction to R, R as a calculator, Plotting of Mathematical Functions in R, Writing functions in R, Two dimensional plots.	2
2	Numerical Computation using R: Bisection method, Newton Raphson method, Regular Falsi methods etc. (Using packages and self-written codes)	4
3	Numerical Integration using R: Self written codes on Trapezoidal rule, Simpson's 1/3rd and 3/8 rule. (Self-written codes)	2
4	Solving ordinary differential equations using R, deSolve, solving system of linear ODEs,	4
5	Matrix computations in R: Inverse of matrix, special matrices, solving system of linear equations, generalized inverse, least squares, Eigenvalues and eigenvectors and some selected applications	4
6	Exploring statistical distributions using R: Probability mass functions and Probability density functions, Notion of r, d, p, q (rnorm, dnorm, qnorm, pnorm) related to probability distributions in R. Descriptive Statistics using R: Data types, Data description, data import and export, Basic Statistics using R, data exploration and summary statistics, Histograms, boxplot, stem and leaf plot, normal probability plot, quantile-quantile plot	4
7	Simulating Random numbers: Continuous Univariate Statistical Distribution and their simulation in R, Approximating probabilities by means of simulation, Demonstration of Convergence in Probability Using Simulation, Demonstration of Weak Law of Large Numbers, Demonstration of Central Limit Theorem (concepts covered in MAT 2301)	6
List of Textbooks/ Reference Books		
1	Hans Petter Langtangen (auth.)-A Primer on Scientific Programming with Python-Springer Berlin Heidelberg.	

2	Reema Thareja, Python Programming: Using Problem Solving Approach.
3	David Beazley, Python Cookbook: Recipes for Mastering Python 3.
4	Victor A. Bloomfield, Using R for Numerical Analysis in Science and Engineering, CRC Press.
5	James, G. Witten, D., Hastie, T. and Tibshirani, R. Introduction to Statistical Learning with Applications in R, Springer.
6	Brian Dennis, The R Student Companion, CRC Press, Taylor and Francis Group.
7	Garrett Grolemund, Hands-On Programming with R: Write Your Own Functions and Simulations, Shroff/O'Reilly.
8	Laura Chihara and Tim Hesterberg, Mathematical Statistics and Resampling and R.John Wiley & Sons.
9	Christian P. Robert and George Casella, Introducing Monte Carlo Methods with R, Springer.

Course Outcomes (students will be able to…..)		
CO1	understand basic syntax in Python and R.	
CO2	create their own subroutines in Python.	
CO3	use standard Python library to solve mathematical problems.	
CO4	use R to solve problems in basics probability and statistics.	
CO5	write their own R-programmes to solve problems in mathematics and statistics.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	2	5	5	1	1	3	1	5	2	1	5
CO2	0	2	5	5	1	1	3	1	5	2	2	5
CO3	0	5	5	5	3	3	5	1	5	2	1	5
CO4	0	1	5	5	4	3	5	1	5	3	1	5
CO5	0	5	5	5	3	3	5	5	5	5	3	5

SEMESTER II

	Course Code: MAT 2205	Course Title: Optimization Techniques	Credits = 4		
			L	T	P
	Semester: II	Total contact hours: 60	3	1	0

List of Prerequisite Courses

Applied Linear algebra (MAT 2201), Real Analysis-I (MAT 2202)

List of Courses where this course will be prerequisite

Machine Learning (MAT 2324), Deep Learning and Artificial Intelligence (MAT 2325)

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This M.Sc. program gives special emphasis on the implementation and application of large-scale computational techniques from applied mathematics and statistics. Optimization problems are abundant almost in all real-life problems related to industrial applications.

	Course Contents (Topics and subtopics)	Hours
1	Introduction to Optimization problems and formulations	4
2	**One dimensional Optimization:** Golden Section method, Fibonacci search Method, Polynomial interpolation method, Iterative methods	8
3	**Classical optimization Techniques:** Unconstrained optimization, Constrained Optimizations: Penalty methods, Method of Lagrange multiplier, Kuhn-Tucker method	8
4	**Linear Programming:** Simplex Method, Revised Simplex Method and other advanced Methods, Duality, Dual Simplex Method, Integer Programming Problems	12
5	**Unconstrained Optimization Techniques:** Direct search methods such as Powel's method, Simplex method, etc	4
6	**Gradient Search Methods:** Steepest descent method, Conjugate gradient method, Newton's method, Quasi-Newton's method, DFP, BFGS method etc	12
7	Dynamic Programming Problems	4
8	Genetic Algorithms, Simulated Annealing, Ant Colony Optimization	8

List of Textbooks/ Reference Books

1	Edvin K. P. Chong & Stanislab H. Zak, An Introduction to Optimization, John Wiley.
2	Leunberger, Linear and Nonlinear Programming, Springer
3	Jorge Nocedal, Stephen J. Wright, Numerical Optimization, Springer
4	S.S. Rao, Engineering Optimization: theory and practices, New Age International Pvt. Ltd,
5	K. Deb, Optimization for Engineering Design, Prentice Hall, India
6	L. Davis, Handbook of genetic Algorithm, New York Van Nostrand Reinhold
7	Z. Michaleuwicz, Genetic Algorithm+Data Structure=Evolution Programme, Springer-Verlag
8	R. K. Belew and M. D. Foundations of Genetic Algorithms, Vose, San Francisco, CA: Morgan Kaufmann.

Course Outcomes (students will be able to…..)

CO1	to formulate optimization problems.	
CO2	understand the standard methods to solve unconstrained and constrained optimization problems.	
CO3	understand linear programming problems.	
CO4	solve optimization problems using various algorithms.	
CO5	apply various algorithms in optimization techniques to solve real life problems.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	5	5	5	5	1	3	1	5	1	1	5
CO2	0	5	5	5	4	1	4	1	5	1	1	5
CO3	0	4	5	5	4	1	4	1	5	1	1	5
CO4	0	4	5	5	5	3	4	1	5	1	1	5
CO5	0	5	5	5	5	5	5	5	5	5	2	5

	Course Code: MAT 2207	Course Title: Real Analysis – II	Credits = 4		
			L	T	P
	Semester: II	Total contact hours: 60	3	1	0

List of Prerequisite Courses		
Real Analysis – I (MAT 2202)		
List of Courses where this course will be prerequisite		
Functional Analysis (MAT 2210), Complex Analysis (MAT 2206)		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
This course is a foundation course covering major concepts of Real Analysis and multivariate calculus. Introduced concepts which will be used in almost all the later courses.		
Course Contents (Topics and subtopics)		**Hours**
1	Sigma-algebra of measurable sets. Completion of a measure. Lebesgue Measure and its properties. Non-measurable sets. Measurable functions and their properties.	20
2	Lebesgue integral, Functions of bounded variation and absolutely continuous functions. Monotone Convergence theorem, Fatou's Lemma, Dominated Convergence Theorem, Vitalli Convergence theorem	20
3	Fundamental Theorem of Calculus for Lebesgue Integrals. Product measure spaces, Fubini's theorem	10
4	L^p spaces, duals of L^p spaces. Riesz Representation Theorem for C([a,b]).	10
List of Textbooks/ Reference Books		
1	I. K. Rana, Introduction to Measures and Integration, AMS	
2	H. L. Royden, Real Analysis, 4th Ed. PHI	
3	Bartle, Elements of Integration and Lesbegue Measure, Wiley	
4	Krishna B. Athreya and S. Lahiri, Measure theory and probability theory, Springer Texts in Statistics, Springer Verlag	
5	G. De. Barra, Measure Theory and Integration, New Age Publishers, Second Edition.	
Course Outcomes (students will be able to…..)		
CO1	understand the construction of measure as generalization of notion of length.	
CO2	construct examples of measurable functions, and construct nonmeasurable set	
CO3	understand the notion of Lebesgue integral and compare it with Riemann integral.	
CO4	compute integrals using montotone, dominated convergence theorems.	
CO5	compute the duals of Lp[a,b] and C[a,b].	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	4	1	0	4	3	1	1	5	1	0	5
CO2	5	5	0	0	4	1	2	1	5	1	0	5
CO3	5	4	0	0	4	1	1	1	5	1	0	5
CO4	5	4	1	1	5	2	1	1	5	3	0	5
CO5	5	4	0	0	4	3	1	1	5	2	0	5

	Course Code: MAT 2421	Course Title: Numerical methods	Credits = 4		
			L	T	P
	Semester: II	Total contact hours: 60	3	1	0

List of Prerequisite Courses

List of Courses where this course will be prerequisite

It is a foundation course which will be prerequisite for all the courses related to statistics and applied mathematics.

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This course will introduce various numerical methods which are useful in solving differential equations, solving system of linear equations, understanding of machine learning algorithms etc.

	Course Contents (Topics and subtopics)	Hours
1	Error Analysis and difference table	4
2	**Solution of Algebraic and transcendental equation:** Bisection method, Secant method, Regula-False method, Newton-Raphson method and convergence criteria for these methods.	8
3	**Numerical solution of linear equations:** Gauss-Jacobi, Gauss-Seidel iteration, Successive over relaxation (SOR) and under relaxation method and convergence criteria for these methods.	8
4	**Interpolations:** Lagrange Interpolation, Divided difference, Newton's backward and forward interpolation, Central difference interpolation (Hermite), Cubic Spline interpolation,	8
5	Numerical differentiation, and integration (Trapezoidal rule, Simpsons 1/3 ,3/8 rules). Gauss quadrature formula	6
6	LU decompositions and its applications, Eigenvalue Approximation using Power method, Aitken acceleration. Inverse and shifted inverse power method. Linear least squares.	8
5	**Numerical solution of initial value problems (first and higher order ODE):** Taylor series, Runge-Kutta explicit methods (second and forth order), Predictor–Corrector methods (Adam- Basforth, Adam-Moulton method). Stiff differential equations and its solutions with implicit methods, Numerical Stability, Convergence, and truncation Errors for the different methods.	10
6	Numerical Solution of boundary value problems using initial value method and Shooting techniques (Newton-Raphson and Principle of superposition method).	8

List of Textbooks/ Reference Books

1	M. K. Jain, S. R. K. Iyengar and R. K. Jain: Numerical methods for scientific and engineering computation, Wiley Eastern Ltd. Third Edition.
2	S.S. Sastry, Introductory methods of Numerical analysis, Prentice- Hall of India, New Delhi.
3	D.V. Griffiths and I.M. Smith, Numerical Methods for Engineers, Blackwell Scientific Publications.
4	S.D. Conte and C. deBoor, Elementary Numerical Analysis-An Algorithmic Approach, McGraw Hill.
5	S.C. Chapra, and P.C. Raymond, Numerical Methods for Engineers, Tata Mc Graw Hill.
6	M.K. Jain: Numerical solution of differential equations, Wiley Eastern, 2nd Ed

Course Outcomes (students will be able to…..)

CO1	develop the basic understanding of numerical analysis algorithms.	
CO2	solve initial value and boundary value ODE numerically.	
CO3	find numerical solutions of linear and nonlinear equations.	
CO4	acquire skills to implement algorithms to solve mathematical problems on computer.	
CO5	analyse solution obtained using numerical algorithms.	
CO6	model solve real life problems using ordinary differential equations.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	5	1	5	3	2	1	3	5	1	1	5
CO2	0	5	1	2	1	1	1	1	5	1	1	5
CO3	0	5	1	2	1	1	1	2	5	1	1	5

CO4	0	5	3	2	3	1	4	1	5	1	0	5
CO5	0	5	4	4	4	2	4	1	5	3	1	5

	Course Code: MAT 2322	**Course Title: Statistical Inference**	**Credits = 4**		
			L	**T**	**P**
	Semester: II	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses

Probability Theory (MAT 2321)

List of Courses where this course will be prerequisite

Statistical Computing (MAT 2323), Machine Learning (MAT 2324), Deep Learning and Artificial Intelligence (MAT 2325)

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This course is a foundation course covering major statistical concepts related to theory of point estimation and testing of hypothesis.

	Course Contents (Topics and subtopics)	**Hours**
1	Parametric Point estimation: Finding estimators using method of moments, maximum likelihood. Properties of estimators: Sufficiency, factorization theorem, minimal sufficiency, exponential family and completeness. Ancillary statistics and Basu's theorem. Rao-Blackwell theorem. Unbiased estimates and uniformly minimum variance unbiased estimators. Fisher Information and Cramer-Rao inequality.	24
2	Hypothesis Testing: Method of developing testing procedure: Likelihood Ratio tests, Error probabilities and the power function, Most powerful tests, MP tests, N-P lemma. UMP tests and MLR family. UMPU tests.	16
3	Tests related to normal distribution: Sampling from normal distribution and test for mean, tests on variance, tests on several means, and tests on several variances with practical problems and applications (derivations of these tests as an application of LRT), Chi-square test of independence	12
4	Interval estimation: Method of finding interval estimators, Inversion of test statistics, Pivotal quantities, Size and coverage probability, Connection to Testing of hypothesis	8

List of Textbooks/ Reference Books

1	G. Casella and R. L. Berger, Statistical Inference, Second Edition, Duxbury.
2	K. Md. Ehsanes Saleh and V. K. Rohatgi. An Introduction to Probability and Statistics. Wiley.
3	E. L. Lehmann and G. Casella, Theory of Point Estimation, Second Edition, Springer.
4	E. L. Lehmann and J. P. Romano, Testing Statistical Hypothesis, Third Edition, Springer.
5	L. Wasserman, All of Statistics, Springer.
6	A. M. Gun, M. K. Gupta, B. Dasgupta, An Outline of Statistical Theory, Volume Two, World Press.
7	Daniel Sabanés Bové and Leonhard Held, Applied Statistical Inference: Likelihood and Bayes, Springer

Course Outcomes (students will be able to…..)

CO1	find estimators of parameters for statistical models using different methods.	
CO2	evaluate the performance of an estimator and compare performances of two estimators in inferential problems.	
CO3	develop appropriate testing procedure for a given testing of hypothesis problem and evaluate the performance of the test.	
CO4	apply basic testing of hypothesis techniques to draw inference from real data sets.	
CO5	obtain interval estimate of parameter and solve real life problems.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	1	5	5	0	1	2	1	5	1	1	5
CO2	0	1	5	5	4	1	2	1	5	1	1	5
CO3	0	1	5	5	3	1	3	1	5	4	1	5

CO4	0	1	5	5	4	4	4	4	5	4	3	5
CO5	0	2	5	5	4	4	4	5	5	5	3	5

	Course Code: MAT 2222	**Course Title: Partial Differential Equations**	**Credits = 4**		
			L	**T**	**P**
	Semester: II	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Ordinary differential equation (MAT 2221)		
List of Courses where this course will be prerequisite		
Computational Fluid dynamics (MAT 2402)		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
This subject is fundamental to understand the nature of fluid flows and mathematical modelling of heat and mass transfer phenomena		
Course Contents (Topics and subtopics)		**Hours**
1	First order PDEs: Linear, quasi-linear equations-Method of characteristics, Lagrange method	6
2	Second order PDEs: Classification and Canonical forms of equations in two independent variables, One dimensional wave equation- D'Alembert's solution, Reflection method for half line, Inhomogeneous wave equation, Fourier Method.	10
3	One dimensional diffusion equation: Maximum Minimum principle for the diffusion equation, Diffusion equation on the whole line, Diffusion on the half-line, inhomogeneous equation on the whole line, Fourier method.	10
4	Solution of parabolic, elliptic, and hyperbolic equations using variable separable methods	10
5	Laplace equation: Maximum-Minimum principle, Uniqueness of solutions; Solutions of Laplace equation in Cartesian and polar coordinates-Rectangular regions, circular regions, annular regions; Poisson integral formula.	10
6	Numerical Solutions of PDE's: Numerical Solution of partial differential equations (parabolic and hyperbolic) using explicit and implicit finite difference methods, Numerical stability for explicit and implicit method. Solution of elliptic equation using finite difference methods, Collocation and Galerkin methods, Methods of finite residuals, Finite element formulation for the solution of ODE and PDE, Calculation of element matrices, assembly and solution of linear equations.	14
List of Textbooks/ Reference Books		
1	Renardy and Rogers, An introduction to PDE's, Springer-Verlag.	
2	W. A Strauss Partial, differential equations, An Introduction, Wiley, John & Sons.	
3	Dennis Zill, W. S. Wright, Advanced Engineering Mathematics, Jones & Bartlett.	
4	L.C. Evans, Partial differential equations, Springer.	
5	I. N. Sneddon, Elements of partial differential equations, McGraw-Hill.	
6	K.W. Morton & D.F. Mayers, Numerical solution of partial differential equations, Cambridge, 2nd Edn.	
7	G.D. Smith, Numerical solution of partial differential equations, finite difference methods, Oxford.	
8	J. N. Reddy, An Introduction to Finite Element Methods, McGraw-Hill.	
9	G. D. Smith, Numerical solution of partial differential Equations: Finite difference methods, New York, NY: Clarendon Press.	
Course Outcomes (students will be able to…..)		
CO1	On successful completion of the course, the students should be able to understand standard methods to solve partial differential equations.	
CO2	find numerical solutions of partial differential equations.	
CO3	implement algorithms to solve PDE on computers.	
CO4	analyse analytical and numerical solutions.	
CO5	model and solve real life problems using partial differential equations.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	5	0	5	3	2	2	3	5	1	0	5
CO2	0	5	1	1	1	1	1	0	5	1	0	5
CO3	0	5	1	1	1	1	1	2	5	1	0	5
CO4	0	5	1	1	3	1	4	1	5	0	0	5
CO5	0	5	0	4	4	2	4	1	5	3	1	5

	Course Code:	**Course Title: Elective – I**	**Credits = 4**		
			L	**T**	**P**
	Semester: II	**Total contact hours: 60**	**3**	**1**	**0**

Candidate will have to choose one of the elective subjects offered for that semester from the elective subjects. A consolidated list of all the elective subjects is given at the end.

SEMESTER III

	Course Code: MAT 2210	**Course Title: Functional Analysis**	**Credits = 4**		
			L	**T**	**P**
	Semester: III	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses

Real Analysis – I (MAT 2202), Real Analysis – II (MAT 2207), Applied Linear Algebra (MAT 2201)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This is a foundation course in Applied and Pure Mathematics. A lot of techniques from Functional Analysis are useful in differential equations and numerical methods. This course strengthens mathematical foundation of the students.

	Course Contents (Topics and subtopics)	**Hours**
1	Normed spaces, Continuity of linear maps, Banach spaces	14
2	Inner product spaces, Hilbert spaces, Dual spaces and transposes, Orthonormal basis. Projection theorem and Riesz Representation Theorem	18
3	Hahn-Banach Extension and Separation theorems, Baire Category Theorem, Zabreiko's lemma for subadditive functionals, Uniform Boundedness Principle, Banach Steinhauss Theorem, Closed Graph Theorem, Open Mapping Theorem, Bounded Inverse Theorem as consequences of Zabreiko's Lemma.	14
4	Spectrum of a bounded operator, Examples of compact operators on normed spaces.	14

	List of Textbooks/ Reference Books
1	E. Kreyzig, Introduction to Functional Analysis with Applications, John Wiley & Sons, New York.
2	B.V. Limaye, Functional Analysis, 2ndEdition, New Age International, New Delhi.
3	B.V. Limaye, Linear Functional Analysis for Scientists and Engineers, Springer- Singapore.
4	S. Kumaresan and D Sukumar, Functional Analysis—A First Course, Narosa Publishing House.
5	C. Goffman and G. Pedrick, First Course in Functional Analysis, Prentice Hall.
6	R Bhatia, Notes on functional Analysis, Hindustan Book Agency.

	Course Outcomes (students will be able to…..)	
CO1	prove continuity of Linear operators on normed spaces and give an example of non-continuous operator on infinite dimensional spaces.	
CO2	study the Zabreiko's Lemma and apply it to prove the major theorems of functional analysis.	
CO3	compute duals of certain spaces.	
CO4	compute Hahn Banach extensions of linear operators.	
CO5	compute spectrum of bounded operators and identify compact operators.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	3	0	1	4	1	1	0	5	0	1	5
CO2	5	3	0	0	5	0	2	0	5	2	1	5
CO3	5	0	3	3	5	0	1	0	5	0	1	5
CO4	5	0	1	0	4	2	2	1	5	2	1	5
CO5	5	0	1	0	4	2	1	1	5	0	1	5

	Course Code: MAT 2323	**Course Title: Statistical Computing**	**Credits = 4**		
			L	**T**	**P**
	Semester: III	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Probability Theory (MAT 2321), Statistical Inference (MAT 2322), Programming Lab (MAP 2521)		
List of Courses where this course will be prerequisite		
Deep Learning and Artificial Intelligence (MAT 2325)		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
With an enormous increase of the large-scale computational methods in science and engineering, applied mathematicians must get exposure to various statistical methods. This course aims to give the students exposure to computer intensive statistical methods. It also enables students to understand various simulation methods and Monte carlo techniques which are in the core of application of mathematics to solve real life problems.		
Course Contents (Topics and subtopics)		**Hours**
1	Estimation of cumulative distribution function and statistical functionals	6
2	Approximation of the distribution of nonlinear functions of random variables and functions of random sample: (Central Limit Theorem and First order and second order Delta method, Extension to multivariate delta method)	6
3	Random variable generation: Simulation of Random numbers following some specific distribution; Probability Integral transform; Accept/Reject algorithm; Metropolis algorithm, Gibbs sampler	8
4	Monte Carlo Integration, Importance Sampling, Variance reduction, Riemann Approximations, Laplace Approximations, Saddle point approximation, Acceleration using Antithetic variables, control variates and conditional expectations, Statistical simulation using R	10
5	Bootstrap methods: Bootstrap variance estimation, Bootstrap confidence intervals, Jacknife.	6
6	Elements of Bayesian inference: Bayesian philosophy, Prior distribution, posterior distribution, computing posterior point estimate, conjugate prior distribution, Jeffrey's prior, multi-parameter problems and Bayesian testing, large sample properties of Bayes estimators (emphasis on real data problems and use of packages in R or Python for Bayesian inference)	12
7	Nonparametric curve estimation: Histogram estimator, Kernel density estimation, bias-variance trade-off, smoothing using orthogonal functions: density estimation and regression problems	12
List of Textbooks/ Reference Books		
1	Larry Wasserman, All of Statistics: A concise course in statistical inference.	
2	Daniel Sabanés Bové and Leonhard Held, Applied Statistical Inference: Likelihood and Bayes, Springer.	
3	Christian P. Robert George Casella, Monte Carlo Statistical Methods, Springer.	
4	Eric A. Suess, Bruce E. Trumbo, Introduction to Probability Simulation and Gibbs Sampling with R, Springer.	
5	James R. Thompson, Simulation A Modeler's Approach, John Wiley & Sons, Inc.	
6	Reuven Y. Rubinstein, Dirk P. Kroese, Simulation and the Monte Carle method, John Wiley & Sons, Inc.	
7	Christian P Robert and George Casella, Introducing Monte Carlo Methods with R, Springer	
8	Larry A. Wasserman, All of Nonparametric Statistics, Springer	
9	R. A. Thisted, Elements of Statistical Computing.	
Course Outcomes (students will be able to…..)		
CO1	approximate the distribution of nonlinear functions of random variables using large sample theory.	
CO2	simulate random numbers from some statistical distribution using different algorithms.	
CO3	apply Monte Carlo simulation to estimate model parameters and draw inference.	
CO4	understand basic principles of Bayesian statistics and apply them in parameter estimation problems.	
CO5	apply resampling methods to approximate confidence intervals and variance of estimators.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	0	5	5	3	1	3	1	5	1	1	5
CO2	0	0	5	5	4	3	4	1	5	3	1	5
CO3	0	0	5	5	3	0	3	1	5	1	1	5
CO4	0	1	5	5	4	2	5	5	5	1	3	5
CO5	0	1	5	5	3	5	5	5	5	4	3	5

	Course Code: MAT 2324	**Course Title: Machine Learning**	**Credits = 3**		
			L	**T**	**P**
	Semester: III	**Total contact hours: 45**	**2**	**1**	**0**
List of Prerequisite Courses					
Applied Linear Algebra (MAT 2201), Probability Theory (MAT 2321), Statistical Inference (MAT 2322), Programming Lab (MAP 2521), Optimization techniques (MAT 2205)					
List of Courses where this course will be prerequisite					
Deep learning and Artificial intelligence (MAT 22325)					
Description of relevance of this course in the M.Sc. Engineering Mathematics Program					
Machine learning algorithms are in the core of modern computational techniques. This course helps the students to understand the mathematical and statistical concepts behind the machine learning algorithms. Students also get exposure to various challenges in solving real life problem.					

	Course Contents (Topics and subtopics)	**Hours**
1	Machine Learning Concepts: Mean Square Error (MSE), Training Error, Test Error, Bias-variance trade-off, Measuring the quality of fit, Regression Diagnostics, Understanding the concept of model flexibility and prediction accuracy, Universal behaviour of Training and Test MSE. Case study of linear regression with K-nearest neighbour regression. (Emphasize on simulating the universal patterns using simulated realizations)	6
2	Model Selection and Regularization: Validation set approach, Leave-One-Out-Cross-Validation, K-fold cross validation, Best subset selection, Forward Selection, Backward selection, Hybrid selection, shrinkage methods: Ridge regression, Lasso.	6
3	Decision Trees, Bagging and Boosting, Random Forests, Gradient Boosting, Adaboost	8
4	Project Pursuit Regression, Fitting Neural Networks, Selection of number of hidden layers, Computational considerations	4
5	Gaussian Discriminant Analysis, Naive Bayes, Support Vector Machines: support vector classifier, SVM and for regression, Kernel tricks	9
6	Multivariate methods: Principal Component Analysis, Factor Analysis, Principal component regression, K-means clustering, Hierarchical Clustering, Multi-dimensional scaling	12
7	Software Component: R/Python	

	List of Textbooks/ Reference Books
1	Andreas C. Müller and Sarah Guido, Introduction to Machine Learning with Python: David Barber A Guide for Data Scientists, O'Reilly Media.
2	Hands on Machine Learning with R by Bradley Boehmke and Brandon Greenwell, CRC Press.
3	Introduction to Statistical Learning with Application in R by James, G., Witten, D., Hastie, T. and Tibshirani, R.
4	All of Statistics: A concise course on Statistical Inference by Larry Wasserman.
5	The Elements of Statistical Learning by Jerome H. Friedman, Robert Tibshirani, and Trevor Hastie, Springer.
6	Ethem Alpaydin, Introduction to Machine Learning, The MIT Press, Cambridge.
7	Ian H. Witten, Eibe Frank, Mark A. Hall, Data Mining: Practical Machine Learning Tools and Techniques by Elsevier

8	Machine Learning: A Probabilistic Perspective (Adaptive Computation and Machine Learning series) by Kevin P. Murphy.	
	Course Outcomes (students will be able to…..)	
CO1	understand advantages of machine learning algorithms.	
CO2	apply machine learning techniques to solve regression problems involving real data.	
CO3	apply machine learning techniques to solve classification problems involving real data.	
CO4	apply dimension reduction methods to solve problems involving real data.	
CO5	use software to build machine learning models and interpret the results.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	2	5	5		2	2	0	5	0	0	5
CO2	0	2	5	5	3	5	5	5	5	4	0	5
CO3	0	2	5	5	3	5	5	5	5	4	0	5
CO4	0	1	5	5	2	5	5	5	5	4	4	5
CO5	0	1	5	5	2	5	5	5	5	4	4	5

	Course Code: MAT 2206	Course Title: Complex Analysis	Credits = 4		
			L	T	P
	Semester: III	Total contact hours: 60	3	1	0

	List of Prerequisite Courses	
Real Analysis – I (MAT 2202), Real Analysis – II (MAT 2207)		
	List of Courses where this course will be prerequisite	
	Description of relevance of this course in the M.Sc. Engineering Mathematics Program	
This is a foundation course of Mathematics. Many techniques from this course will be used in later courses.		
	Course Contents (Topics and subtopics)	**Hours**
1	Instruction to complex number system, stereographic projection, Analytic functions, Cauchy Riemann Equations, Elementary functions, Conformal mappings, Fractional linear Transformations.	15
2	Complex integration, Cauchy's theorem, Cauchy's integral formula, Liouville's theorem, Morera's Theorem, Cauchy-Goursat Theorem	15
3	Uniform convergence of sequences and series, Taylor and Laurent series, isolated singularities and residues, Classification of singularities, Residue theorem, Evaluation of real integrals	20
4	Maximum Modulus Principle, Argument Principle, Rouche's theorem	10
	List of Textbooks/ Reference Books	
1	J. B. Conway, Functions of One Complex Variable, 2nd Edition, Narosa, New Delhi.	
2	T.W. Gamelin, Complex Analysis, Springer International Edition.	
3	M. J. Ablowitz and A.S. Fokas Complex variables, Introduction and applications, Cambridge texts in applied mathematics.	
4	Danis G. Zill & Patric D. Shanahan, Complex Analysis: A First Course with Applications, Jones and Bartlett Pub.	
5	John H. Mathews & Russel D. Howell, Complex Analysis for Mathematics and Engineering, Jones and Bartlett Pub.	
	Course Outcomes (students will be able to…..)	
CO1	identify analytic functions.	
CO2	apply Cauchy's theorem to compute complex integrals.	
CO3	obtain power series and Laurent series for analytic and non-analytic functions.	
CO4	classify singularities of a function.	
CO5	compute real improper integrals using residue theorems and compute zeros of functions.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	5	1	2	4	4	3	1	5	2	0	5
CO2	5	5	1	0	4	0	3	1	5	1	0	5
CO3	5	5	1	0	3	1	4	1	5	1	0	5
CO4	5	5	0	0	4	3	3	0	5	3	1	5
CO5	5	5	1	2	3	3	4	1	5	2	1	5

	Course Code:	**Course Title: Elective – II**	**Credits = 4**		
			L	**T**	**P**
	Semester: III	**Total contact hours: 60**	**3**	**1**	**0**

Candidate will have to choose one of the elective subjects offered for that semester from the elective subjects. A consolidated list of all the elective subjects is given at the end.

	Course Code: MAP 2701	**Course Title: Project Seminar**	**Credits = 2**		
			L	**T**	**P**
	Semester: III	**Total contact hours: 60**	**0**	**0**	**4**

The Project seminar is concerned with detailed and critical analysis of literature related to a topic on which the candidate is expected to do project in the final semester. The study will be supervised by a faculty member and student is expected to continue to do project under his guidance in next semester. Candidate is expected to submit a report as per guidelines provided below which will be evaluated by the supervisor and an external examiner from the Department/Industry based on the presentation made by the candidate. A suitable combination of the marks for report and presentation will be considered for the final evaluation.

The division of marks will be as follows:
Internal Marks (20) + Final Marks based on presentation (20) + Project report (10) = Total marks (50)

Suggestive Guideline:
1. Literature survey (Research papers/ reading course/ adopt new computational tools/ etc.)
2. Report must be prepared using LaTex and the format will be provided by the department.
3. Name of the student, title of the problem and year of examination must be indicated on the top cover. The name of the supervisor (only initials) must appear on the bottom right corner of the top cover.
4. Typographical errors in the report must be corrected by the student. The student will be discredited for any omission in the report.
5. The list of references should be arranged in alphabetical order of the names of authors. In the text, the reference should be cited with author's name and year.
6. The last date for submission will NOT be extended on any grounds whatsoever.
7. There must not be any acknowledgment about the guidance by the faculty in the report.
8. Candidates are not permitted to do word to word copying from published articles or books.

Course Outcomes (students will be able to…..)		
CO1	Collect information from the literature and summarize them.	
CO2	Understand the research problem and identify possible gaps.	
CO3	Write neat report following the guidelines.	
CO4	Propose a defined plan of research.	
CO5	Adapt new mathematical/statistical/computational/programming topics which are not covered in the subjects taught.	

List of Prerequisite Courses	
All Courses in M.Sc. in Engineering Mathematics	

List of Courses where this course will be prerequisite	
Projects (MAP 2702)	

Description of relevance of this course in the M.Sc. Engineering Mathematics Program
This course enables students to gather scientific information on a particular topic, analyze the information and present a written and oral summary on that topic. This enables the students to function in a professional environment later on in their career

	Course Code: MAP 2522	**Course Title: Software Lab**	**Credits = 2**		
			L	**T**	**P**
	Semester: III	**Total contact hours: 60**	**0**	**0**	**4**

List of Prerequisite Courses	
Progamming Lab (MAP 2521)	
List of Courses where this course will be prerequisite	
Description of relevance of this course in the M.Sc. Engineering Mathematics Program	
This course gives special emphasis on computational mathematics and its application in various real-life problems. This course gives exposure to the students to experiment with mathematical software and their use in real life problems.	

	Course Contents (Topics and subtopics)	**Hours**
1	Introduction to Computer Algebra Systems (CAS) and Sagemath.	2
2	Plotting 2d and 3d graphs in Sagemath.	4
3	Use of solve function to solve various type of equations in Sagemath.	2
4	Exploring calculus of single and multi-variables in Sagemath	8
5	Working with vectors, matrices and vector spaces in Sagemath	8
6	Linear transforms and its applications in Sagemath.	4
7	Inner product and least square problems in Sagemath.	6
8	Applications of eigenvalues and eigenvectors in SageMath.	6
9	Singular Value Decomposition and its applications in Sagemath.	4
10	Exploring concepts in number theory and group theory in Sagemath.	4
11	Use of MATLAB to explore concepts in optimization techniques and differential equations.	12

	List of Textbooks/ References
1	Sang-Gu Lee, Ajit Kumar, Robert Beezer and others, Calculus, KyonMoon Publications, S. Korea
2	Paul Zimmermann, Computational Mathematics with Sage (available online from sagemath.org)
3	Sang-Gu Lee, Ajit Kumar and other, BigBook: Linear Algebra by (Free online)
4	Robert Beezer, A First Course in Linear Algebra (Free online, http://buzzard.ups.edu/)
5	Ajit Kumar and Vikas Bist, Group Theory—An Expedition with SageMath, Narosa Publications
6	Gregory Bard, Sage for undergraduate (available online from sagemath.org)
7	An Introduction to SAGE Programming: With Applications to SAGE Interacts for Numerical Methods by Razvan A Mezei, Wiley.
8	George A. Anastassiou, Razvan A. Mezei, Numerical Analysis Using Sage, Springer
9	José Miguel David Báez-López, David Alfredo Báez Villegas, MATLAB handbook with applications to mathematics, science, engineering, and finance-CRC Press.
10	Mircea Anciiu, Practical Optimization with MATLAB, Cambridge Scholars Publishing

	Course Outcomes (students will be able to…..)	
CO1	use Sagemath for doing basic numerical computations and symbolics computations.	
CO2	plot graphs of 2d and 3d objects in Sagemath	
CO3	create Sagemath subroutines to solve mathematical problems.	
CO4	explore concepts in calculus, linear algebra and group theory using Sagemath	
CO5	use MATLAB to solve problems in Differential equations and Optimization problems.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	1	4	5	4	2	2	4	0	5	0	1	5
CO2	0	4	5	4	0	0	4	0	5	0	0	5
CO3	0	5	4	4	0	0	4	1	5	0	1	5
CO4	1	4	5	5	2	2	4	2	5	2	1	5
CO5	0	5	4	5	2	3	4	2	5	3	3	5

SEMESTER IV

	Course Code: MAT 2223	Course Title: Combinatorics	Credits = 4		
			L	T	P
	Semester: IV	Total contact hours: 60	3	1	0

List of Prerequisite Courses		
Modern Algebra (MAT 2204)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
This course will provide the necessary mathematical foundation and exposure to problems related to applications of discrete mathematics in different domains.		

	Course Contents (Topics and subtopics)	Hours
1	Sets, Multisets, Binomial Coefficients, and important identities	4
2	Recurrences, Fibonacci numbers and others	3
3	Permutations, cycles in permutations, Stirling numbers of both kinds	5
4	Set Partitions: Exponential Generating function, Dobinski's formula, orthogonality of matrices	4
5	Integer Partitions: Euler's identity, conjugate partitions, bijective proofs, Euler's pentagonal Number theorem	4
6	Generating functions, ordinary and exponential, examples of OGFS, composition of generating functions, exponential formula for EGFS.	5
7	Graph Theory: Walks, paths, distances, Adjacency matrix of graphs, distance matrix of trees and the Graham Pollak Theorem, Counting Spanning trees, Matrix Tree theorem, Matching Theory	20
8	Exploration of concepts in combinatorics and graphs theory using Sagemath	15

	List of Textbooks/ Reference Books
1	Miklos Bona, Introduction to Enumerative Combinatorics, McGraw-Hill.
2	Miklos Bona, Walk through Combinatorics, World Scientific.
3	Paul Zimmerman, Computational Mathematics with SageMath (free online on sagemath.org).
4	M. Aigner, A Course in Enumeration. Springer.
5	C. Berge. Principles of Combinatorics. Academic Press.
6	J. M. Harris, J. L. Hirst, M. J. Mossinghoff, Combinatorics and Graph Theory, Springer.
7	Istvan Mezo, Combinatorics and number theory of counting sequences, CRC Press.

	Course Outcomes (students will be able to…..)	
CO1	understand fundamental mathematical objects such as sets, functions and permutations.	
CO2	solve problems involving various counting principles.	
CO3	apply combinatorial ideas to practical problems.	
CO4	understand and use idea of modelling problems using Graph Theory.	
CO5	solve problems in combinatorics and graph theory using Sagemath.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	0	1	3	3	2	2	0	5	0	2	5
CO2	5	1	1	1	0	5	2	2	5	3	0	5
CO3	0	1	1	1	0	0	5	1	5	0	0	5
CO4	0	1	1	1	4	4	2	1	5	1	0	5
CO5	0	5	5	5	4	4	2	1	5	3	2	5

	Course Code: MAT 2305	Course Title: Stochastic Process	Credits = 4		
			L	T	P
	Semester: IV	Total contact hours: 60	3	1	0

List of Prerequisite Courses

Probability Theory (MAT 2321), Statistical Inference (MAT 2322), Real Analysis-I (MAT 2202), Real Analysis-II (MAT 2207)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This course deals with various real-life application of probability theory in biology, medicine, finance and engineering. Several methods taught in Mathematics and Statistics courses in the previous semesters will be used in dealing with problems and case studies in this course.

	Course Contents (Topics and subtopics)	Hours
1	Discrete-Time Markov Models: Discrete-Time Markov Chains, Transient Distributions, Occupancy Times, Limiting Behavior, First-Passage Times.	10
2	Poisson Processes, Superposition of Poisson Processes, Thinning of a Poisson Process, Compound Poisson Processes.	8
3	Continuous-Time Markov Chains, Transient Analysis: Uniformization, Occupancy Times, Limiting Behavior, First-Passage Times, Birth and Death Processes, Examples of Birth and Death process	10
4	Branching process, Discrete Time Branching Processes, Generating Function Relations for Branching Processes, Extinction Probabilities	8
5	Martingales: super martingales and sub martingales, Optional Sampling theorem, Martingale convergence theorem and their applications	8
6	Examples of some stationary processes Mean square prediction of stochastic process, Ergodic theory and stationary process.	6
7	Brownian motion and Gaussian process, properties of Brownian motion, Some Transformation of Brownian motion, Brownian motion with drift, The Ornstein-Uhlenbeck process	10

List of Textbooks/ Reference Books

1	Sheldon M. Ross. Stochastic Processes, 2nd Ed, Wiley.
2	C. W. Gardiner, Handbook for Stochastic Methods for Physics, Chemistry, and the Natural Sciences. Third Edition. Springer-Verlag, Berlin.
3	Karlin and Taylor. A First course in Stochastic Process. Academic Press (Volume-I).
4	Karlin and Taylor. A First course in Stochastic Process. Academic Press (Volume-II).
5	J. Medhi, Stochastic Processes, New Age International.
6	Robert P. Dobrow, Introduction to stochastic processes with R-John Wiley & Sons.
7	Normal T. J. Bailey, The elements of Stochastic Processes with Application to the Natural Sciences. John Wiley & Sons, Inc.
8	Fima C Klebaner, Introduction to Stochastic Calculus with Applications. 2nd Ed., Imperial College Press.
9	Bernt Oksendal, Stochastic Differential Equations: An Introduction with Applications, Springer.

Course Outcomes (students will be able to…..)

CO1	compute limiting and stationary distribution of Markov chains.	
CO2	understand the theory and applications of Poisson process.	
CO3	apply probability generating functions in computations related to branching process.	
CO4	apply basic inference techniques for making predictions of stochastic process.	
CO5	understand the properties of Brownian motion and its application in various real-life problems.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	2	5	5	0	0	2	0	5	0	0	5
CO2	0	2	5	5	4	0	2	1	5	0	0	5
CO3	0	1	5	5	3	1	3	2	5	4	0	5

CO4	0	1	5	5	4	4	4	4	5	4	3	5
CO5	0	2	5	5	4	4	4	5	5	5	3	5

	Course Code: **MAT 2325**	Course Title: **Deep Learning and Artificial Intelligence**	Credits = 3		
			L	**T**	**P**
	Semester: IV	**Total contact hours: 45**	**2**	**1**	**0**

List of Prerequisite Courses

Probability Theory (MAT 2321), Statistical Inference (MAT 2322), Programming Lab (MAP 2521), Optimization techniques (MAT 2205), Machine Learning (MAT 2324)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This course gives the students exposure to large scale mathematical computations in solving real life problems.

	Course Contents (Topics and subtopics)	**Hours**
1	Machine learning basics and introduction to deep learning	6
2	Deep Neural networks, Architecture design, backpropagation, and other differentiation algorithms	10
3	Regularization for deep learning, Bagging, and other ensemble models	6
4	Optimization techniques for training deep learning models, Approximate second-order methods, algorithm for adaptive learning rates	6
5	Convolutional Networks	4
6	Recurrent Networks, Long short-term memory, optimization for long terms dependencies	6
7	Applications of Deep Learning: Computer vision, Speech recognition, Natural language processing	7
8	Software Implementation: R/Python/MATLAB	

List of Textbooks/ Reference Books

1	Ian Goodfellow and Yoshua Bengio and Aaron Courville, Deep Learning, MIT Press.
2	The Elements of Statistical Learning by Jerome H. Friedman, Robert Tibshirani, and Trevor Hastie, Springer.
3	Josh Patterson, Adam Gibson, Deep Learning: A Practitioner's Approach.
4	Ovidiu Calin, Deep Learning Architectures: A Mathematical Approach.
5	Kevin P. Murphy, Machine Learning: A Probabilistic Perspective.
6	John Paul Mueller, Luca Massaron, Deep Learning For Dummies.
7	Venkata Reddy Konasani, Shailendra Kadre, Machine Learning and Deep Learning Using Python and TensorFlow, Mc Graw Hill.

Course Outcomes (students will be able to…..)

CO1	understand basic principles of Deep Learning and artificial Intelligence.
CO2	understand the mathematical concepts behind deep learning algorithms.
CO3	understand statistics and optimization principles in deep neural networks.
CO4	apply deep learning algorithms in solving real life problems.
CO5	apply Deep Learning Algorithms using R or Python.

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	2	5	5	0	2	2	0	5	0	1	5
CO2	0	2	5	5	3	5	5	5	5	4	1	5
CO3	0	0	5	5	3	5	5	5	5	4	1	5
CO4	0	0	5	5	2	5	5	5	5	4	4	5

CO5	0	0	5	5	2	5	5	5	5	4	4	5

	Course Code: MAT 2402	**Course Title: Computational Fluid Dynamics**	**Credits = 5**		
			L	**T**	**P**
	Semester: IV	**Total contact hours: 60**	**3**	**2**	**0**

List of Prerequisite Courses		
Ordinary Differential Equation (MAT 2221), Partial Differential Equations (MAT 2222). Numerical methods (MAT 2421)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
This course deals with several numerical and computational techniques of Applied Mathematics having direct implications to industrial and other real life applications.		
	Course Contents (Topics and subtopics)	**Hours**
1	Introduction to tensor calculus and curvilinear coordinates	8
2	Classification of fluids (Newtonian and Non-Newtonian fluids). Deformation, Strain tensor, Rate of deformation tensor, material derivative, steady and unsteady flows, streamline and stream function, conservation of mass, potential flows.	6
3	Relation between stress and rate of strain, constitutive equation (Newtonian & Non-Newtonian fluids), Stokes' hypothesis, Derivation of Navier-Stokes equation in Cartesian, Cylindrical Polar and Spherical Polar system for laminar flows.	10
4	Flow in some simple cases: Fully developed flow between two parallel plates and through circular pipe, Flow between two concentric cylinders, flow between two concentric rotating cylinders.	6
5	Grid generation, Structured and Unstructured grid generation methods	6
6	Solution of Systems of Linear Algebraic Equations using iterative methods such as: Gauss-Seidel iterative method, Line by line TDMA, ADI (Alternating direction implicit) method etc. Stability and convergence of numerical methods. Finite Volume Discretization of 1-D, 2-D and 3-D problems. Application of various iterative methods to the discretized Equations.	10
7	Finite volume discretization of convection-diffusion problem: Central difference scheme, Upwind scheme, Power-law scheme, Generalized convection-diffusion formulation.	4
8	Finite volume discretization of two-dimensional convection-diffusion problem, the concept of false diffusion, Discretization of the Momentum Equation: Stream Function Vorticity approach and Primitive variable approach, Staggered grid, SIMPLE, SIMPLER algorithm etc.	10
9	Tutorial to be performed using mathematical software such as MATLAB, ASPEN, FLUENT	15
List of Textbooks/ Reference Books		
1	Pijush K. Kundu and Ira M Cohen, Fluid Mechanics, Elsevier.	
2	G. K. Batchelor, An Introduction to Fluid Dynamics, Cambridge University Press.	
3	S.W. Yuan, Foundations of Fluid Mechanics, Prentice Hall.	
4	R. W. Whorlow, Rheological Technique, Ellis Horwood Ltd.	
5	R.B. Bird, W.E. Stewart E.N., Lightfoot, Transport Phenomena, John Wiley & Sons.	
6	Fletcher C.A.J, Computational Techniques for Fluid Dynamics, Volumes I & II, Springer-Verlag.	
7	C. Hirsch, Numerical Computation of Internal and External Flows, Volume I & II, Wiley.	
8	J. C. Tannehill, D. A. Anderson and R. H. Pletcher, Computational Fluid Mechanics and Heat Transfer, McGraw-Hill.	
9	G. D. Smith, Numerical Solution of Partial Differential Equations: Finite Difference Methods, New York, NY: Clarendon Press.	
10	M. Schafer-Computational engineering- Introduction to numerical methods.	
11	M. Farrashkhalvat, J Miles, Basic Structured Grid Generation, Elsevier.	

12	S. V. Patankar, Numerical Heat Transfer and Fluid Flow, Hemisphere Pub.
13	John. D. Anderson, Jr., Computational Fluid Dynamics, The Basics with Applications, McGraw-Hill.

Course Outcomes (students will be able to…..)		
CO1	develop basic knowledge in tensor analysis and application to various coordinate system	
CO2	develop basic understanding for obtaining governing equation of motion for some specific flow problems. And obtain velocity profiles and drag coefficient.	
CO3	generate the grids in different coordinate system and apply various iterative methods to a large system of linear and non-linear algebraic equations, which will guarantee the convergence of the system.	
CO4	discretise ODE and PDE using finite volume method and will be able to solve the discretised linear equation using various iterative methods along with boundary conditions.	
CO5	apply finite volume method to discretise laminar fluid flow problems using upwind, hybrid and power-law schemes along with SIMPLE and SIMPLER algorithms and use of various programming languages such as: PYTHON, MAT LAB, FLUENT etc. to obtain the numerical solutions to the discretised	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	5	0	0	0	4	4	1	5	0	0	5
CO2	0	5	1	0	0	0	5	1	5	0	0	5
CO3	0	5	1	0	0	0	5	0	5	1	0	5
CO4	0	5	1	0	4	5	4	0	5	1	1	5
CO5	0	5	0	0	5	5	5	2	5	5	1	5

	Course Code:	**Course Title: Elective – III**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV	**Total contact hours: 60**	**3**	**1**	**0**

Candidate will have to choose one of the elective subjects offered for that semester from the elective subjects. A consolidated list of all the elective subjects is given at the end.

	Course Code: MAP 2702	**Course Title: Project**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV	**Total contact hours: 60**	**0**	**0**	**8**

This would be concerned with the continuation of the research project executed in the third semester and the exact work plan will be decided in consultation with the project guide. At the end of the project, the candidate is expected to submit a report as per similar guidelines provided for MAP 2701 above which will be evaluated by the research guide and an external examiner from the Department/Industry/Institute based on the presentation made by the candidate. A suitable combination of the marks for report and presentation will be considered for the final evaluation.

Marks distribution:
Internal Marks (40) + Final Presentation (20) + Report (20) + Overall (20) = Total (100)

Electives in Semester – II
(Elective – I)

	Course Code: MAT 2601	Course Title: Graph Theory	Credits = 4		
			L	**T**	**P**
	Semester: II (Elective - I)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Modern Algebra (MAT 2204)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		

	Course Contents (Topics and subtopics)	**Hours**
1	Preliminaries: Graphs, isomorphism, sub graphs, matrix representations, degree, operations on graphs, degree sequences.	6
2	Connected graphs and shortest paths: Walks, trails, paths, connected graphs, distance, cut vertices, cut-edges, blocks, connectivity, weighted graphs, shortest path algorithms.	8
3	Trees: Characterizations, number of trees, minimum, spanning trees.	6
4	Special classes of graphs: Bipartite graphs, line graphs, chordal graphs	6
5	Eulerian graphs: Characterization, Fleury's algorithm, Chinese-postman-problem	4
6	Hamilton graphs: Necessary conditions and sufficient conditions	4
7	Independent sets and cliques, coverings, matching: Basic equations, matching in bipartite graphs, Halls Theorem, perfect matching, defect form of Halls Theorem, greedy and approximation algorithms	10
8	Vertex colourings: Chromatic number and cliques, greedy colouring algorithm, colouring of chordal graphs, Brook's theorem	10
9	Directed graphs: Out-degree, in-degree, connectivity, orientation, Eulerian directed graphs, Hamilton directed graphs, tournaments.	6

	List of Textbooks/ References
1	Bondy and U.S.R.Murty: Graph Theory and Applications (Freely downloadable from Bondy's website; Google-Bondy).
2	D.B.West: Introduction to Graph Theory, Prentice-Hall of India/Pearson.
3	J.A.Bondy and U.S.R.Murty: Graph Theory, Springer.
4	R.Diestel: Graph Theory, Springer(low price edition).
5	Agnarsson, Geir, and Raymond Greenlaw, Graph Theory: Modeling, Applications, and Algorithms, Pearson.
6	R. Balakrishnan, K. Ranganathan, A textbook of Graph theory. Second edition. Springer.
7	Gary Chartrand, Ping, Zhang, Introduction to Graph Theory. Tata McGraw-Hill Publishing Company Limited.

	Course Outcomes (students will be able to…..)	
CO1	understand important classes of problems in graph theory.	
CO2	formulate and prove fundamental theorems on trees, matchings, connectivity, colorings, plane and hamiltonian graphs.	
CO3	summarize the basic properties of trees and their application.	
CO4	describe and apply some basic algorithms for graphs.	
CO5	use graphs as a tool to model real-life problems.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	5	4	5	3	4	4	0	5	0	0	5
CO2	5	5	5	5	0	0	3	0	5	0	0	5
CO3	5	3	4	4	0	0	4	0	5	0	0	5
CO4	3	4	4	5	2	5	4	0	5	2	1	5
CO5	4	4	4	5	2	5	5	0	5	4	1	5

	Course Code: MAT 2602	**Course Title: Topology**	**Credits = 4**		
			L	**T**	**P**
	Semester: II (Elective - I)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Real Analysis – I (MAT 2202)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		

	Course Contents (Topics and subtopics)	Hours
1	Cartesian Products, Finite Sets, Countable and Uncountable Sets, Infinite Sets and Axiom of Choice, Well Ordered Sets.	4
2	Topological Spaces: Basis for a topology, Order topology, Subspace topology, Product topology	8
3	Closed and open sets, Limit Points, Continuity, Metric Topology and Quotient Topology	12
4	Connectedness: Connected spaces, Connected, Subspaces of Real Line, Components and Local Connectedness, Simply connectedness	8
5	Compactness: Compact spaces, Compact Subspaces of the Real Line, Limit point compactness, Local Compactness	8
6	Countability Axioms, Separation axioms: Normal Spaces, Urysohn's Lemma (without proof), Titetz Extension Theorem, Metrization Theorem, Tychonoff's Theorem	8
7	One-point Compactification, Complete metric spaces and function spaces, Characterization of compact metric spaces, equicontinuity, Ascoli-Arzela Theorem	8
8	Baire's Category Theorem	4
	If time permits, an introduction to Fundamental Groups may be covered	

	List of Textbooks/ Reference Books
1	J. R. Munkres, Topology, 2nd Edition, Pearson Education (India).
2	M. A. Armstrong, Basic Topology, Springer (India).
3	Stefan Waldman, Topology: An introduction, Springer.
4	G. F. Simmons, Introduction to Topology and Modern Analysis, McGraw-Hill.
5	S. Kumaresan, Topology of Metric Spaces, 2nd Ed., Narosa Publishing House.

	Course Outcomes (students will be able to…..)	
CO1	understand different topological spaces with metric spaces as special cases.	
CO2	identify and learns basic notions of continuity, connectedness and compactness in arbitrary topological spaces.	
CO3	characterise compact spaces in arbitrary topological spaces.	
CO4	identify Hausdorff, regular and normal spaces.	
CO5	prove an analogy of Bolzano Weirstrass theorem (Arzela Ascolis) theorem for functions in the space of continuous functions.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	2	1	1	5	1	1	0	5	0	0	5
CO2	5	3	1	1	3	0	1	0	5	0	0	5
CO3	5	1	1	1	4	0	1	1	5	0	0	5
CO4	5	2	1	1	3	2	1	0	5	4	0	5
CO5	5	3	1	1	3	2	1	0	5	4	0	5

	Course Code: MAT 2603	**Course Title: Number Theory**	**Credits = 4**		
			L	**T**	**P**
	Semester: II (Elective – I)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses

Modern Algebra (MAT 2204)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

	Course Contents (Topics and subtopics)	Hours
1	Divisibility: Division Algorithms, Prime and Composite Numbers, Fibonacci and Lucas Numbers, Fermat Numbers	8
2	Greatest Common Divisor: GCD, Euclidean Algorithm, Fundamental Theorem of Arithmetic, LCM, Linear Diophantine Equations	8
3	Congruences: Congruence modulo n, Linear Congruences, Divisibility Tests, Chinese Remainder Theorem and its applications, Wilson's, Fermat Little and Euler's Theorems with Applications	12
4	Multiplicative Functions: Euler-phi function, Tau and Sigma Functions, Perfect Numbers, Möbius Function, Mersenne Primes	8
5	Primitive Roots and Indices: Order of positive integers, Primality tests, Primitive Roots of Primes, Algebra of Indices	8
6	Quadratic Congruence: Quadratic Residues, Legendre Symbols, Quadratic Reciprocity	8
7	Continued Fractions: Finite continued Fractions, Infinite continued Fractions	4
8	Nonlinear Diophantine Equations	4

List of Textbooks/ Reference Books

1	Thomas Koshy, Elementary Number Theory with applications, Academic Press, 2nd Ed.
2	Kenneth H. Rosen, Elementary Number Theory and Its Applications, Addison Wesley, 5th Ed.
3	G.A. Jones and J.M. Jones, Elementary Number Theory, Springer
4	Niven and Zuckerman, An introduction to the Theory of Numbers, Wiley

Course Outcomes (students will be able to…..)

CO1	define and interpret the concepts of divisibility, congruence, greatest common divisor, prime, and prime factorization.
CO2	apply the Law of Quadratic Reciprocity and other methods to classify numbers as primitive roots, quadratic residues, and quadratic non-residues.
CO3	collect and use numerical data to form conjectures about the integers.
CO4	produce rigorous arguments (proofs) cantered on the material of number theory,
CO5	apply concepts in number theory to solve real life problems.

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	4	2	1	2	1	2	0	5	1	0	5
CO2	5	4	2	3	1	0	4	0	5	1	0	5
CO3	5	5	4	2	2	0	4	0	5	1	0	5
CO4	3	5	2	3	3	1	2	1	5	2	0	5
CO5	4	4	4	4	3	3	5	4	5	3	1	5

	Course Code: MAT 2604	Course Title: Matrix Computations	Credits = 4		
			L	T	P
	Semester: II (Elective – I)	Total contact hours: 60	3	1	0

List of Prerequisite Courses		
Applied Linear Algebra (MAT 2201), Numerical Methods (MAT 2401)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
	Course Contents (Topics and subtopics)	**Hours**
1	Review of vector spaces, linear transformation and inner product spaces	8
2	Matrix Norms, Singular Value decomposition, Matrix limit and Markov chain and applications	4
3	Sensitivity of linear Systems, Sparse matrices and sparse solutions	6
4	Least Square Problems and various methods to solve	8
5	Eigenvalue Problems: Unsymmetric and symmetric eigenvalue problems	8
6	Positive Matrices and its applications, Square room of positive semidefinite matrices, Schur product theorem.	8
7	Location and Perturbation of Eigenvalues	6
8	Matrix Tensors: Introduction to tensor, rank of tensors, tensor product and decompositions, vectorization and matricization of tensors with applications	12
	List of Textbooks/ Reference Books	
	Lloyd N. Trefethen and David Bau, Numerical Linear Algebra, SIAM.	
	Gene H. Golub and Charles van Loan., Matrix Computations, Johns Hopkins University Press.	
	D.S. Watkins, Fundamentals of Matrix Computations, Wiley.	
	J. Demmel, Applied Numerical Linear Algebra, SIAM.	
	Course Outcomes (students will be able to…..)	
CO1	understand basic concepts in matrix computations.	
CO2	standard matrix norms and its applications.	
CO3	apply least square methods to real life mathematical problems.	
CO4	understand eigenvalue problems and its applications.	
CO5	understand tensor data and its applications to large scale data.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	4	2	1	2	1	2	2	5	1	0	5
CO2	5	4	2	3	1	0	4	2	5	1	0	5
CO3	5	5	4	2	2	0	4	1	5	1	0	5
CO4	3	5	2	3	3	1	2	1	5	2	1	5
CO5	4	4	4	4	3	3	5	5	5	3	1	5

Electives in Semester – III
(Elective – II)

	Course Code: MAT 2621	Course Title: Cryptography	Credits = 4		
			L	T	P
	Semester: III (Elective – II)	Total contact hours: 60	3	1	0

List of Prerequisite Courses		
Modern Algebra (MAT 2204), Number Theory (MAT 2603)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		

	Course Contents (Topics and subtopics)	Hours
1	Need for cryptography: Online transactions, Perfect secrecy, eavesdropping attacks, ciphertext attacks, Block cipher codes, Hash functions. Brief introduction to number theory, Euclidean algorithm, Euler's totient function, Fermat's theorem and Euler's generalization, Chinese Remainder Theorem, primitive roots and discrete logarithms, Quadratic residues, Legendre and Jacobi symbols.	8
2	**Private key cryptography**: Stream ciphers, Block ciphers, DES and differential and linear cryptanalysis, Advanced encryption standards, Collision resistant hashing, Authenticated encryption: security against active attacks.	10
3	**RSA public key cryptosystems:** RSA system, primality testing, survey of factoring algorithms. Other public key cryptosystems: El Gamal public key cryptosystem, algorithms for discrete log problem.	10
4	Block ciphers, Stream ciphers and Hash Functions	5
5	**Digital Signatures Schemes:** Definition of digital signatures, RSA based digital signatures, Signatures from the Discrete-Logarithm Problem, Certificates and Public-Key Infrastructures	12
6	Mathematical Software: Sagemath can be used to explore concepts in Cryptography. Students may be encouraged to develop Sage subroutine to solve problems in Cryptography.	15

	List of Textbooks/ Reference Books
1	N. Koblitz, A Course in Number Theory and Cryptography, Springer
2	A. Menezes, P. C. Van Oorschot and S. A. Vanstone, Handbook of Applied Cryptography, CRC Press
3	D. Stinson, Cryptography: Theory and Practice, CRC Press
4	J. Katz and Y. Lindell, Introduction to Modern Cryptography, CRC Press
5	Heiko Knopse, A Course in Cryptography, CRC Press
6	Alasdair McAndrew, Introduction to Cryptography with Open-Source Software, CRC Press.

	Course Outcomes (students will be able to…..)	
CO1	understand various concepts in cryptography techniques.	
CO2	understand various security applications.	
CO3	apply various public key cryptography to real life application.	
CO4	implement Hashing and Digital Signature techniques	
CO5	implement cryptography algorithms Sagemath and create models.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	1	1	3	3	2	2	1	5	1	2	5
CO2	5	1	1	2	0	5	2	2	5	3	0	5
CO3	1	1	1	3	0	1	5	1	5	0	0	5
CO4	1	1	1	4	4	4	2	1	5	1	0	5
CO5	1	5	5	5	4	4	2	3	5	3	2	5

	Course Code: MAT 2622	Course Title: Finite Element Method	Credits = 4		
			L	T	P
	Semester: III (Elective – II)	Total contact hours: 60	3	1	0

List of Prerequisite Courses	
Ordinary differential equations (MAT 2221), Partial differential equations (MAT 2222), Numerical methods (MAT 2421)	
List of Courses where this course will be prerequisite	
Description of relevance of this course in the M.Sc. Engineering Mathematics Program	

	Course Contents (Topics and subtopics)	Hours
1	Calculus of Variations: Variational formulation - Rayleigh-Ritz minimization	6
2	Weighted Residual Approximations: Point collocation, Galerkin and Least Square methods and their applications to the solution of ODE and PDE	10
3	Finite Element Procedures: Finite Element Formulations for the solutions of ordinary and partial differential equations: Calculation of element matrices, assembly and solution of linear equations.	16
4	Finite Elements: One dimensional and two-dimensional basis functions, Lagrange and serendipity family elements for quadrilaterals and triangular shapes, co-ordinate transformation, integration over a Master Triangular and Rectangular element.	16
5	Application of Finite element Method: Finite element solution of Laplace and Poisson equations over rectangular and nonrectangular and curved domains. Applications to some problems in fluid mechanics and in other engineering problems	12
6	If time permits, attempts should be made to solve some problems on fluid mechanics and in other engineering problems using Finite element Method.	(if time permits)

	List of Textbooks/ Reference Books
1	O. C. Zienkiewiez and K. Morgan, Finite Elements and approximation, John Wieley.
2	P.E. Lewis and J.P. Ward, The Finite element method- Principles and applications.
3	Addison Weley and L. J. Segerlind, Applied finite element analysis (2nd Edition), John Wiley.
4	J. N. Reddy, An Introduction to the Finite Element Method, McGraw Hill, NY.
5	I.J. Chung, Finite Element Analysis in Fluid Dynamics, McGraw Hill Inc.

	Course Outcomes (students will be able to…..)	
CO1	have basic knowledge in calculus of variation and able to solve ODE and PDE using variational methods	
CO2	obtain finite element formulation for ODE using linear and quadratic elements and able to assembly all the elements. Further using given boundary condition, the solution to a given ODE can be obtained.	
CO3	obtain finite element formulation for PDE using triangular and rectangular elements and also able to assembly all the elements for a given domain. Further, using given boundary condition the solution to a given PDE can be obtained	
CO4	find coordinate transformation from an irregular to a regular domain which will facilitate the computation of irregular domain.	
CO5	apply the Finite Element Method to some practical problems in 1-D and 2-D problems.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	5	0	1	1	4	4	0	5	0	0	5
CO2	0	5	0	1	1	0	5	0	5	0	0	5
CO3	0	5	0	0	0	0	5	0	5	0	0	5
CO4	0	5	0	0	4	5	4	0	5	0	0	5
CO5	0	5	0	0	5	5	5	2	5	5	0	5

	Course Code: MAT 2623	**Course Title: Operation Research**	**Credits = 4**
			L | **T** | **P**
	Semester: III (Elective – II)	**Total contact hours: 60**	**3** | **1** | **0**

	List of Prerequisite Courses		
	Applied Linear Algebra (MAT 2201), Real Analysis-I (MAT 2202). Optimization techniques (MAT 2205)		
	List of Courses where this course will be prerequisite		
	Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
	Course Contents (Topics and subtopics)		**Hours**
1	Operations Research: Introduction of operation research using historical perspective		4
2	Linear Programming Problem: Simplex Methods, Revised simplex method, two phase simplex method, Big-M Method, Karmakar Method, Sensitivity analysis and Duality		12
3	Integer Programming		8
4	Dynamic programming, Characteristics of dynamic programming, Dynamic programming approach for Priority Management employment smoothening, capital budgeting, Stage Coach/Shortest Path, cargo loading and Reliability problems		8
5	Transportation and Assignment Problems: Transportation Problems definition, Linear form, Solution methods: North-west corner method, least cost method, Vogel's approximation method. Degeneracy in transportation, Modified Distribution method, Unbalanced problems and profit maximization problems. Transhipment Problems Assignment problems and Travelling sales man problems.		12
6	Inventory Control: Inventory classification, Different cost associated to Inventory, Economic order quantity, Inventory models with deterministic demands, ABC analysis.		4
7	Queuing Theory: Basis of Queuing theory, elements of queuing theory, Kendall's Notation, Operating characteristics of a queuing system, Classification of Queuing models and preliminary examples.		8
8	Network models		4
	List of Textbooks/ Reference Books		
1	Hamdy Taha, Operations Research: An Introduction, Pearson.		
2	A M Natarajan, P Balasubramani, A Tamilarasi, Operations Research, Pearson Education Inc.		
3	Wayne L. Winston and M. Venkataramanan, Introduction to Mathematical Programming, 4th Ed, Cengage Learning.		
4	Eiselt, H. A., Sandblom, Carl-Louis, Operations Research-A Model Based Approach, Springer.		
5	Harvir Singh Kasana, Krishna Dev Kumar, Introductory Operations Research, Theory and Applications, Springer.		
	Course Outcomes (students will be able to…..)		
CO1	understand basic concepts in the subject of operation research.		
CO2	solve linear programming problems arising in science and engineering.		
CO3	apply various algorithms to solve linear programming problems.		
CO4	formulate real life problems as linear programming or dynamic programming problems.		
CO5	analyse linear programming problems arising in science and engineering.		

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	2	5	5	0	2	2	0	5	0	0	5
CO2	0	1	5	5	3	5	5	5	5	4	0	5
CO3	1	2	5	5	3	5	5	5	5	4	0	5
CO4	0	3	5	5	2	5	5	5	5	4	4	5
CO5	0	5	5	5	2	5	5	5	5	4	4	5

	Course Code: MAT 2624	**Course Title: Mathematical Finance-I**	**Credits = 4**		
			L	**T**	**P**
	Semester: III (Elective – II)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Probability Theory (MAT 2321), Real Analysis-I (MAT 2202)		
List of Courses where this course will be prerequisite		
Mathematical Finance – II (MAT 2643)		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
Course Contents (Topics and subtopics)		**Hours**
1	The Time Value of Money: Compound interest with fractional compounding, NPV, IRR, and Descartes's Rule of Signs, Annuity and amortization theory, The Dividend Discount Model, Valuation of Stocks, Valuation of bonds	8
2	Portfolio Theory: Markowitz portfolio model, Two-security portfolio, N-security portfolio, Investor utility, Diversification and the uniform Dirichlet distribution	8
3	Capital Market Theory and Portfolio Risk Measures: The Capital Market Line, The CAPM Theorem, The Security Market Line, The Sharpe ratio, VaR	12
4	Modeling the Future Value of Risky Securities: Binomial trees, Continuous-time limit of the CRR tree, Stochastic process: Brownian motion and geometric Brownian motion, Itô's formula.	8
5	Forwards, Futures, and Options: No arbitrage and the Law of One Price, Forwards, Futures, Option type, style, and payoff, Put-Call Parity for European options, Put-Call Parity bounds for American options	12
6	The Black-Scholes-Merton Model: Black-Scholes-Merton (BSM) formula, Partial differential equation approach to the BSM formula: the BSM Partial differential equation Continuous-time, risk-neutral approach to the BSM formula, Binomial-tree approach to the BSM formula, Delta hedging, Implied volatility.	12
List of Textbooks/ Reference Books		
1	S.M. Ross, An introduction to Mathematical Finance, Cambridge University Press.	
2	A. J. Prakash, R. M. Bear, K. Dandapani, G.L. Gahi, T.E. Pactwa and A.M. Parchigari, The return Generating Models in Global Finance, Pergamon Press.	
3	J. Hull, Options, Futures, and Other Derivatives (Pearson Prentice Hall, Upper Saddle River.	
4	S. M. Ross, Applied Probability: Models with Optimization Applications, Holdenday.	
5	S. Roman, Introduction to the Mathematics of Finance Springer, New York.	
Course Outcomes (students will be able to…..)		
CO1	Understand basic idea of different financial instruments	
CO2	Understand various concepts related to portfolio theory.	
CO3	Model financial instruments using stochastic processes and Ito formula	
CO4	Apply probability concepts for pricing options, future etc.	
CO5	Apply Black-Scholes model for option pricing	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	1	4	2	1	2	1	2	0	5	0	0	5
CO2	1	4	2	3	1	0	4	0	5	0	0	5
CO3	2	5	4	2	2	0	4	0	5	0	0	5
CO4	1	5	2	3	3	1	2	0	5	2	3	5
CO5	1	4	4	4	3	3	5	0	5	3	4	5

	Course Code: MAT 2625	Course Title: Multivariate Analysis	Credits = 4		
			L	T	P
	Semester: III (Elective – II)	Total contact hours: 60	3	1	0

List of Prerequisite Courses		
Probability Theory (MAT 2321), Statistical Inference (MAT 2322), Programming Lab (MAP 2521)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
With an enormous increase of the large-scale computational methods in science and engineering, applied mathematicians must get exposure to various statistical methods. This course aims to give the students exposure to the theory of multivariate statistics and their applications in real life problems.		
Course Contents (Topics and subtopics)		**Hours**
1	Review of linear algebra, review of multivariate distributions, multivariate normal distribution and its properties, distributions of linear and quadratic forms	8
2	Tests for partial and multiple correlation coefficients and regression coefficients and their associated confidence regions. Data analytic illustrations	8
3	Wishart distribution (definition, properties).	6
4	Construction of tests, union-intersection and likelihood ratio principles, inference on mean vector, Hotelling's T^2, MANOVA	8
5	Inference on covariance matrices. Discriminant analysis. Principal component analysis and factor analysis	10
6	Multivariate Linear Regression, Practical on the above topics using statistical packages for data analytic illustrations,	10
7	Clustering, Distance methods and Ordination and application to real data sets.	10
List of Textbooks/ Reference Books		
1	T. W. Anderson, An Introduction to Multivariate Statistical Analysis.	
2	R. A. Johnson and D. W. Wichern, Applied Multivariate Statistical Analysis.	
3	K. V. Mardia, J. T. Kent and J. M. Bibby, Multivariate Analysis.	
4	M. S. Srivastava and C. G. Khatri, An Introduction to Multivariate Statistics.	
Course Outcomes (students will be able to…..)		
CO1	Understand the geometry of sample and various properties of multivariate normal distribution	
CO2	Apply various testing procedures for multivariate data	
CO3	Derive the sampling distribution of statistics and apply them to construct testing procedures in a multivariate set up	
CO4	Understand regression and clustering method in multivariate set up.	
CO5	Apply various multivariate methods using statistical packages to solve real life problems	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	0	5	5	3	1	3	1	5	1	1	5
CO2	0	0	5	5	4	3	4	1	5	3	1	5
CO3	0	0	5	5	3	0	3	1	5	1	1	5
CO4	0	1	5	5	4	2	5	5	5	1	3	5
CO5	0	1	5	5	3	5	5	5	5	4	3	5

	Course Code: MAT 2626	**Course Title: Design and Analysis of Experiments**	**Credits = 4**		
			L	**T**	**P**
	Semester: III (Elective – II)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Applied Linear Algebra (MAT 2201), Probability Theory (MAT 2321), Statistical Inference (MAT 2322)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		

	Course Contents (Topics and subtopics)	**Hours**
1	Gauss-Markoff Theorem, Randomization and Replication, Analysis of one-way classification model. Analysis of two-way classification model with equal number of observations per cell with and without interactions. Analysis of two-way classification model with unequal number of observations per cell without interactions	16
2	Analysis of BIBD. Analysis of covariance in one way and two-way classification models, Testing of hypotheses for estimable parametric functions.	10
3	General factorial experiments, 2Kdesign, confounding in 2K design, Partial confounding and total confounding	10
4	Response surface methodology (RSM): linear and quadratic model, stationary point, central composite designs (CCD), ridge systems, multiple responses, concept of rotatable designs, Box-Behnken design, optimality of designs, simplex lattice designs, simplex centroid designs	16
5	Taguchi methods: concept of noise factors, concept of loss function, S/N ratio, orthogonal arrays	8
6	Software: R/Python/MATLAB	

	List of Textbooks/ Reference Books
1	Montgomery, D.C. Design and Analysis of Experiments, Wiley.
2	Dean, A. and Voss, D. Design and Analysis of Experiments, Springer
3	George E. P. Box, Draper N.R. Empirical Model-Building and Response Surfaces, Wiley
4	W. W. Hines, D. C. Montgomery, Probability and Statistics in Engineering. John Wiley.
5	Rao, C. R. Linear Statistical Inference and Its Applications, Wiley

	Course Outcomes (students will be able to…..)	
CO1	perform statistical analysis of one-way and two-way classified data.	
CO2	analyse data coming from factorial experiments.	
CO3	understand basic principles of response surface methodology and apply them in real life problems.	
CO4	apply Taguchi methods to optimize designs.	
CO5	use statistical software to analyse real data and interpret the results.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	0	5	5	0	2	2	0	5	0	0	5
CO2	0	0	5	5	3	5	5	5	5	4	0	5
CO3	0	0	5	5	3	5	5	5	5	4	0	5
CO4	0	0	5	5	2	5	5	5	5	4	4	5
CO5	0	0	5	5	2	5	5	5	5	4	4	5

	Course Code: MAT 2627	Course Title: Mathematical Biology	Credits = 4		
			L	T	P
	Semester: III (Elective – II)	Total contact hours: 60	3	1	0

List of Prerequisite Courses

Ordinary Differential Equations (MAT 2221), Partial differential equations (MAT 2222)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

	Course Contents (Topics and subtopics)	Hours
1	Basic population growth models, concepts of birth, death and migration, concept of closed and open populations, unconstrained population growth for single species, exponential, logistic, Gompertz, ricker growth models, Allee model, Basic dynamical analysis of growth profiles	12
2	Harvest models, bifurcations and break points, discrete time and delay models, stable and unstable fixed points	12
3	Concepts of interacting populations, predator-prey models, host-parasitoid system, functional response, stability of equilibrium points, Poincare-Bendixson's theorem	12
4	Global bifurcations in predator-prey models, discrete time predator-prey models, competition Models	12
5	Concept of optimal control theory connected to harvest models, An overview of age-structured models and spatially structured models, concept of stochastic population models and study of some standard stochastic models in population biology	12

List of Textbooks/ Reference Books

1	Mark Kot, Elements of Mathematical Ecology, Cambridge University Press, Cambridge.
2	Murray, J. D. 1989. Mathematical Biology, Springer-Verlag, Berlin.
3	Horst R. Thieme, Mathematics in Population Biology, Princeton University Press.
4	Josef Hofbauer, Karl Sigmund, Evolutionary games and population dynamics, Cambridge University Press.
5	Eric Renshaw, Modelling Biological Populations in Space and Time. Cambridge University Press.
6	Stevens, M. Henry, A Primer in Ecology with R, Springer.

Course Outcomes (students will be able to…..)

CO1	analyse the mathematical models describing single population dynamics.
CO2	analyse the mathematical models for interactive population dynamics.
CO3	understand basic bifurcation theory and apply in population dynamics problems.
CO4	analyse basic stochastic population dynamics and compute stationary distribution.
CO5	understand the basic optimal control problem and its application in harvesting models.

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	5	0	0	1	4	4	1	5	1	0	5
CO2	0	5	0	0	1	1	5	1	5	1	0	5
CO3	0	5	0	0	1	1	5	3	5	1	0	5
CO4	0	5	0	0	4	5	4	0	5	0	0	5
CO5	0	5	0	0	5	5	5	2	5	5	0	5

	Course Code: MAT 2628	**Course Title: Signal processing**	**Credits = 4**		
			L	**T**	**P**
	Semester: III (Elective – II)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Probability Theory (MAT 2321), Functional Analysis (MAT 2210)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
	Course Contents (Topics and subtopics)	**Hours**
1	Review of Linear Continuous-Time Signal Processing: Fourier methods, Laplace transform, convolution, frequency/time domain processing. Passive and active continuous filters	8
2	Sampling and Reconstruction: Sampling theorem, aliasing, quantization, sampled data systems, cardinal (Whitaker) reconstruction, zero, first, second order hold reconstructors, interpolators, non-resetting reconstructors, matched filtering. Interpolation and decimation.	8
3	Discrete-Time Signal Processing: The z transform, difference equations, relationship between F(z) and F*(jw), mappings between s-domain and z-domain, inverse z transform. Discrete–time stability.	8
4	Discrete Spectral Analysis: The DFT and its relationship to the continuous FT, the FFT and implementations (decimation in time and frequency), radix-2 implementation, leakage, windowing. Uses of the DFT: convolution — (overlap and add, select savings), correlation. Random processes, power spectral density (PSD) estimation — methods of smoothing the periodogram (Welch's method, windowing the correlation function, etc). ARMA methods.	10
5	Real-Time Simulation Methods Using Difference Equations: Impulse-, step-, ramp-invariant simulations. Tustin's method, matched poles/zeros, bilinear transform methods. Error analysis.	8
6	Filter Design — Continuous and Discrete: Butterworth, elliptic, Chebyshev low-pass filters. Low-pass design methods based on continuous prototypes. Realizations. Conversion to high-pass, band-pass, band-stop filters. Discrete-time filters: IIR and FIR. Linear phase filters. Frequency sampling filters.	10
7	Statistical Signal Processing: Linear prediction, adaptive filters (LMS), recursive least-squares, Nonparametric power spectral density estimation	8
List of Textbooks/ Reference Books		
1	Steven B. Damelin, Willard Miller, Jr, The Mathematics of Signal Processing.	
2	Proakis, John G., and Dmitris K. Manolakis. Digital Signal Processing. 4th ed. Upper Saddle River, NJ: Prentice Hall.	
3	Oppenheim, Alan V., Ronald W. Schafer, and John R. Buck. Discrete-Time Signal Processing. 2nd ed. Upper Saddle River, NJ: Prentice Hall	
Course Outcomes (students will be able to…..)		
CO1	Understand the fundamental principles of sampling ideas, Z-transform, discrete frequency related to DSP	
CO2	Understand spectral analysis and estimate the power spectral density by different methods.	
CO3	Understand the designing of filters and test it	
CO4	Understand various real time simulation methods and apply them for real life problems	
CO5	Understand various prediction algorithm for statistical signal processing	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	4	2	1	2	1	2	1	5	0	0	5
CO2	1	4	2	3	1	0	4	1	5	0	0	5
CO3	1	5	4	2	2	0	4	1	5	0	0	5
CO4	1	5	2	3	3	1	2	1	5	2	0	5
CO5	0	4	4	4	3	3	5	1	5	3	1	5

	Course Code: MAT 2629	Course Title: Momentum, Heat and Mass Transfer	Credits = 4		
			L	T	P
	Semester: III (Elective – II)	Total contact hours: 60	3	1	0

List of Prerequisite Courses

Ordinary Differential Equation (MAT 2221), Partial Differential Equations (MAT 2222). Numerical methods (MAT 2421)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This course deals with several numerical and computational techniques of Applied Mathematics having direct implications to industrial and other real life applications.

	Course Contents (Topics and subtopics)	Hours
1	Introduction to tensor calculus and curvilinear coordinates	8
2	Classification of fluids (Newtonian and Non-Newtonian fluids). Deformation, Strain tensor, Rate of deformation tensor, material derivative, steady and unsteady flows, streamline and stream function, conservation of mass, potential flows.	8
3	Relation between stress and rate of strain, constitutive equation (Newtonian & Non-Newtonian fluids), Stokes' hypothesis, Derivation of Navier-Stokes equation in Cartesian, Cylindrical Polar and Spherical Polar system for laminar flows.	12
4	Flow in some simple cases: Fully developed flow between two parallel plates and through circular pipe, Flow between two concentric cylinders, flow between two concentric rotating cylinders.	8
5	Dynamic similarity, derivation of laminar boundary layer equations (using order analysis), Bondary layer flow past a semi-infinite flat plate and wedge using momentum integral method.	8
6	Conduction of heat. Fourier law of heat transfer and application to one dimensional and two-dimensional problems. Convection of heat. Derivation of equation of energy for convective flows in Cartesian and cylindrical Polar coordinates, and application to some simple internal flows.	8
7	Thermal boundary layer flow past a flat plate and heat transfer in some internal flows	8

List of Textbooks/ Reference Books

1	K. Kundu Pijush, Fluid Mechanics, Elsevier.
2	G. K. Batchelor, An Introduction to Fluid Dynamics, Cambridge University Press.
3	H. Schlichting, Klaus Gersten, Boundary-Layer Theory, Springer-Verlag.
4	S.W. Yuan, Foundations of Fluid Mechanics, Prentice Hall.
5	R. W. Whorlow, Rheological Technique, Ellis Horwood Ltd.
6	R.B. Bird, W.E. Stewart E.N., Lightfoot, Transport Phenomena, John Wiley & Sons.
7	Bennet and Myers, Momentum, Heat and Mass Transfer, Mcgraw Hill, Chemical Engineering Series, 1982.
8	I.G. Currie, Fundamental Mechanics of Fluids, Third edition, 1993,

Course Outcomes (students will be able to…..)

CO1	develop basic knowledge in tensor analysis and application to various coordinate system.	
CO2	develop basic understanding for obtaining governing equation of motion for some	

	specific flow problems.	
CO3	obtain drag coefficient on flow past a rigid body.	
CO4	calculate the heat transfer coefficient and distribution in different materials using heat conduction method.	
CO5	calculate the heat transfer coefficient and distribution in a fluid flow problem.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	5	1	1	0	4	4	0	5	0	0	5
CO2	0	5	0	1	0	0	5	0	5	0	0	5
CO3	0	5	0	0	0	0	5	0	5	0	0	5
CO4	0	5	0	0	4	5	4	0	5	0	0	5
CO5	0	5	0	0	5	5	5	2	5	5	0	5

Electives in Semester – IV
(Elective – III)

	Course Code: MAT 2641	**Course Title: Dynamical Systems**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV (Elective – III)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses

Ordinary differential equations (MAT 2221), Partial differential equations (MAT 2222), Numerical methods (MAT 2421)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This course enables the students to apply the theory of ordinary and partial differential equations to solve real life problems arising from engineering, biology, medicine etc.

	Course Contents (Topics and subtopics)	**Hours**
1	Linear and nonlinear discrete dynamical systems: Recurrence relations, Leslie model, Flows and maps. Phase space. Orbits. Fixed points, logistic map, bifurcation diagram and Feigenbaum number, Graphical analysis of orbits of one-dimensional maps, Period doubling root to chaos, example from other branches.	12
2	Planar Systems: Canonical forms, Eigenvectors defining stable and unstable manifolds, Phase portraits, Linearization and Hartman's theorem, Construction of phase plane diagram.	12
3	Equilibrium points, Stable and unstable nodes. Saddle point. Stable and unstable foci. Centre. Lyapunov and asymptotic stability.	8
4	Limit cycles: Existence and uniqueness of limit cycles in the plane, stability of limit cycles, Poincare- Bendixson theorem, worked examples from ecology, disease models.	8
5	Bifurcation theory: Bifurcation of nonlinear systems, Multistability, bistability, Saddle-node bifurcation. Pitchfork bifurcation, Period doubling bifurcation, Hopf bifurcation	12
6	Three dimensional autonomous systems and chaos: Linear systems and canonical forms, The Lorenz equations.	8
	Mathematical software: Mathematica/ MATLAB	

List of Textbooks/ Reference Books

1	L.Perko, Differential Equations and Dynamical Systems, Vol. 7, 2nd Ed., Springer Verlag.
2	Stephen Lynch, 2014. Dynamical Systems with Applications using MATLAB. Springer.
3	Yuri A. Kuznetsov, 1998. Elements of Applied Bifurcation Theory, Second Edition, Springer.
4	Alligood, Sauer, and Yorke. Chaos: An Introduction to Dynamical Systems. Springer, Springer-Verlag New York.
5	Rudiger Seydel, Practical Bifurcation and Stability analysis. Springer (3rd Ed).
6	James T Sandefur, Discrete dynamical systems Theory and applications, Clarendon press.
7	M W Hirsch and S Smale - Differential Equations, Dynamical Systems, Academic.
8	R. Clark Robinson. An Introduction to Dynamical Systems Continuous and Discrete, Second edition. American Mathematical Society, Rhode Island.

Course Outcomes (students will be able to…..)

CO1	understand the basic dynamical behaviour of dynamical systems governed by difference equations.	
CO2	understand the basic dynamical behaviour of dynamical systems governed by differential equations.	
CO3	understand local and global bifurcation phenomena in nonlinear systems.	
CO4	use symbolic mathematical software to analyse dynamical systems.	
CO5	apply theories of dynamical systems to solve real life problems.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	1	5	0	0	2	4	4	0	5	1	0	5
CO2	1	5	0	0	1	1	5	1	5	2	0	5

CO3	0	5	0	1	2	1	5	1	5	2	0	5
CO4	0	5	0	0	4	5	4	1	5	1	0	5
CO5	0	5	0	0	5	5	5	4	5	5	0	5

	Course Code: MAT 2642	**Course Title: Integral Transforms**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV (Elective – III)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Real Analysis – II (MAT 2207), Complex Analysis (MAT 2206), Functional Analysis (MAT 2210)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
This course gives the students ideas of various transforms that have immense applications in science and engineering, including probability and statistics.		
	Course Contents (Topics and subtopics)	**Hours**
1	Basic concepts of integral transforms. Fourier transforms: Introduction, basic properties, applications to solutions of Ordinary Differential Equations (ODE), Partial Differential Equations (PDE).	10
2	Laplace transforms: Convolution, differentiation, integration, inverse transform, Tauberian Theorems, Watson's Lemma, solutions to ODE, PDE including Initial Value Problems (IVP) and Boundary Value Problems (BVP).	10
3	Hankel Transforms: Introduction, properties and applications to PDE Mellin transforms: Introduction, properties, applications; Generalized Mellin transforms. Hilbert transforms in complex plane, applications; asymptotic expansions of 1-sided Hilbert transforms.	8
4	Stieltjes Transform: definition, properties, applications, inversion theorems, properties of generalized Stieltjes transform. Legendre transforms: Intro, definition, properties, applications	8
5	Z Transforms: Introduction, definition, properties; dynamic linear system and impulse response, inverse Z transforms, summation of infinite series, applications to finite differential equations	8
6	Radon transforms: Introduction, properties, derivatives, convolution theorem, applications, inverse radon transform.	8
7	Wavelet Transform: Discussion on continuous and discrete, Haar, Shannon and Daubechies Wavelets.	8
	List of Textbooks/ Reference Books	
1	Sudhakar Nair, Advanced Topics in Applied Mathematics for Engg. & Physical Science, 1st edition, cambridge:	
2	Gilbert Strang, Introduction to Applied Mathematics, Cambridge Press	
3	J. Spanier and K. B. Oldham, Fractional Calculus Theory and Applications of Differentiation and Integration to Arbitrary Order, 1st Edition, Elsevier:	
4	M. Abramowitz & I. Stegun Handbook of Mathematical Functions, Dover.	
	Course Outcomes (students will be able to…..)	
CO1	solve ode and partial differential equations using Fourier Transforms.	
CO2	solve ode and partial differential equations using Laplace Transforms.	
CO3	learn about Hankel, Mellin Transforms and Hilbert Transforms.	
CO4	solve difference equations using Z transforms.	
CO5	understand wavelet and radon Transforms.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	3	1	1	4	1	2	0	5	0	0	5

CO2	5	3	1	1	5	1	2	0	5	2	0	5
CO3	5	0	3	3	5	1	1	0	5	0	0	5
CO4	5	0	1	1	4	2	2	1	5	0	0	5
CO5	5	0	1	1	4	2	1	3	5	0	0	5

	Course Code: MAT 2643	**Course Title: Mathematical Finance-II**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV (Elective – III)	**Total contact hours: 60**	**3**	**1**	**0**

	List of Prerequisite Courses	
Mathematical Finance – I (MAT 2624), Probability Theory (MAT 2321)		
	List of Courses where this course will be prerequisite	
	Description of relevance of this course in the M.Sc. Engineering Mathematics Program	
This course gives students an exposure to applications of mathematics in baking and finance section. Students get the exposure to stochastic differential equation, Ito calculus and pricing of various financial instruments.		
	Course Contents (Topics and subtopics)	**Hours**
1	Review of Probability Spaces and Convergence concepts, Filtrations, Expectations, Change of Measures	8
2	Brownian motion calculus, Ito Integral and its properties, Ito processes and Stochastic differentials, Ito formula for Ito processes and Martingale properties.	12
3	Stochastic Differential Equations, existence, and uniqueness, Backward and Forward equations, numerical techniques for simulation of stochastic differential equations, Multivariate extensions	12
4	Risk neutral pricing in discrete time and continuous time, Stock and FX options, Financial derivatives and arbitrage, Semi martingale market model, Diffusion and Black Scholes model and other examples	10
5	Applications to Bonds, Rates and Options, Bonds and Yield curve, Models based on spot rates, Merton's model and Vasicek's model	10
6	Numerical Schemes for simulation of Stochastic differential equations	8
7	Software: R/Python	
	List of Textbooks/ Reference Books	
1	Fima C Klebaner, Introduction to Stochastic Calculus with Applications, Second edition, Imperial College Press.	
2	Steven Shreve, Stochastic Calculus for Finance I: The Binomial Asset Pricing Model, Springer.	
3	Steven Shreve, Stochastic Calculus for Finance Continuous-Time Models, Springer.	
4	Fima C Klebaner, Introduction to Stochastic Calculus with Applications. Second Edition, Imperial College Press.	
5	Peter E. Kloeden, Eckhard Platen, Henri Schurz, Numerical Solution of SDE Through Computer Experiments.	
6	Stefano M. Iacus, Simulation and Inference for Stochastic Differential Equations With R Examples, Springer.	
7	Zdzisław Brzeźniak and Tomasz Zastawniak, Basic Stochastic Processes: A Course Through Exercises, Springer.	
	Course Outcomes (students will be able to…..)	
CO1	understand basic theory of Ito processes and Ito integrals.	
CO2	solve basic stochastic differential equations and properties of solutions.	
CO3	simulate numerical solutions of some simple stochastic differential equations.	
CO4	apply Ito stochastic calculus for pricing financial instruments.	
CO5	apply the methods to analyse real data sets from financial markets.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	1	4	2	1	2	1	2	0	5	0	0	5
CO2	1	4	2	3	1	0	4	0	5	0	0	5
CO3	2	5	4	2	2	0	4	0	5	0	0	5
CO4	1	5	2	3	3	1	2	2	5	2	3	5
CO5	1	4	4	4	3	3	5	2	5	3	4	5

	Course Code: MAT 2644	**Course Title: Geometry of Curves and Surfaces**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV (Elective – III)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses

Real Analysis – I (MAT 2202), Real Analysis – II (MAT 2207)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

	Course Contents (Topics and subtopics)	**Hours**
1	**Local theory of plane and space curves:** Curvature and torsion of curves, Serret-Frenet formulas, Fundamental Theorem of space curves.	8
2	**Surfaces:** Regular surfaces, Change of parameters, Differentiable functions, Tangent plane, Differential of a map surfaces, Orientable surfaces	8
3	**First and second fundamental Form**: The first fundamental Forms, The Gauss map, The second fundamental forms, Normal and principal curvatures, introduction to ruled and minimal surfaces	12
4	**Curves on Surfaces:** Curvature and torsions, Geodesics	12
5	**The Fundamental Equations of Surfaces:** Tensor Notation, Gauss's Equations and the Christoffel Symbols, Codazzi Equations and the Theorema Egregium, The Fundamental Theorem of Surface Theory	10
6	Gauss-Bonnet theorem and its applications to surfaces of constant curvatures	10

List of Textbooks/ Reference Books

1	Thomas Banchoff and Stephen Lovett, Differential Geometry of Curves and Surfaces, A K Peters, Ltd.
2	Differential Geometry of Curves and Surfaces, by Manfredo P. Do Carmo, Dover Publication
3	Kristopher Tapp, Differential Geometry of Curves and Surfaces, Springer
4	Christian Bär, Elementary Differential Geometry, Cambridge University Press
5	Andrew Pressley, Elementary Differential Geometry, Springer.
6	Differential Geometry: A First Course in Curves and Surfaces, by Theodore Shifrin, which is available free online at http://math474.com/Shifrin

Course Outcomes (students will be able to…..)

CO1	understand basic concepts in theory of plane and space curves.
CO2	understand theory of surfaces.
CO3	solve problems on finding curvature of curves and surfaces.
CO4	apply fundamental forms to compute curvatures of curves and surfaces.
CO5	analyse curves and surfaces and their properties.

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	5	0	0	4	0	4	0	5	0	0	5
CO2	5	5	0	3	4	0	3	0	5	1	0	5
CO3	5	5	1	3	4	0	4	0	5	2	0	5

CO4	5	5	0	0	4	3	5	0	5	1	0	5
CO5	5	5	0	0	4	3	5	0	5	2	0	5

	Course Code: MAT 2645	**Course Title: Convex Optimization**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV (Elective – III)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Applied Linear Algebra (MAT 2201), Optimization Techniques (MAT 2205)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
Course Contents (Topics and subtopics)		**Hours**
1	Introduction to Convex optimization problems	4
2	Convex sets: Affine and convex sets with examples, operations that preserves convexity, generalized inequality, separating and supporting cones, dual cones	10
3	Convex functions: Definition and examples of convex functions, operations that preserves convexity, Conjugate and quasi conjugate functions, log concave and convex function	8
4	Introduction to Convex optimization problems: Generalized optimization and convex optimization problems with examples. Linear and quadratic optimization problems, Geometric programming problems.	10
5	Duality: Lagrange Duality and geometric interpretation, Optimality conditions, perturbation and sensitivity analysis	10
6	Applications of convex optimization: Approximation and fitting, Statistical estimation, Geometric problems	10
7	Interior point methods: Inequality constrained minimization problems, Logarithmic barrier function and central path, The barrier method, Feasibility and phase I methods, Problems with generalized inequalities, Primal-dual interior-point methods	12
	Mathematical software: Python and MATLAB	
List of Textbooks/ Reference Books		
1	Stephen Boyd and Lieven Vandenberghe, *Convex Optimization*, Cambridge University Press	
2	R. T. Rockafellar, Convex Analysis Princeton Univ. Press	
3	Aharon Ben-Tal and Arkadi Nemirovski, Lectures on Modern Convex Optimization: Analysis, Algorithms, and Engineering Applications, SIAM Publication	
4	Jonathan Borwein and Adrian Lewis, Convex Analysis and Nonlinear Optimization, Springer	
Course Outcomes (students will be able to…..)		
CO1	understand basic convex optimization problems.	
CO2	formulate primal and dual of convex optimization problems.	
CO3	solve convex optimization problems using standard algorithms.	
CO4	understand interior point methods to solve convex optimization problems.	
CO5	use concepts in convex optimization to solve real world problems.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	5	5	5	5	1	3	1	5	0	0	5
CO2	0	5	5	5	4	0	4	0	5	1	0	5
CO3	1	4	5	5	4	0	4	0	5	1	0	5
CO4	0	4	5	5	5	0	4	0	5	1	0	5
CO5	0	5	5	5	5	5	5	5	5	5	2	5

	Course Code: MAT 2646	**Course Title: Time Series Analysis**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV (Elective – III)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses

Probability Theory (MAT 2321), Statistical Inference (MAT 2322), Statistical Computing (MAT 2323)

List of Courses where this course will be prerequisite

Description of relevance of this course in the M.Sc. Engineering Mathematics Program

This course enables to students to apply various time series models for forecasting problems which abundant in industry.

	Course Contents (Topics and subtopics)	**Hours**
1	Exploratory analysis of time series: Graphical display, classical decomposition model, concepts of trend, seasonality and cycle, estimation of trend and seasonal components.	4
2	Stationary time series models: Concepts of weak and strong stationarity, AR, MA and ARMA processes – their properties, conditions for stationarity and invertibility, autocorrelation function (ACF), partial autocorrelation function (PACF), identification based on ACF and PACF, estimation, order selection and diagnostic tests.	12
3	Inference with non-stationary models: ARIMA model, determination of the order of integration, trend stationarity and difference stationary processes, tests of nonstationarity i.e., unit root tests – Dickey-Fuller (DF) test, augmented DF test, and Phillips-Perron test	12
4	Forecasting: Simple exponential smoothing, Holt-Winters method, minimum MSE forecast, forecast error, in-sample and out-of-sample forecast.	10
5	Modelling seasonal time series: Seasonal ARIMA models, estimation; seasonal unit root test (HEGY test).	6
6	Simple state space models: State space representation of ARIMA models, basic structural model, and Kalman recursion.	8
7	Spectral analysis of weakly stationary processes: Spectral density function (s. d. f.) and its properties, s. d. f. of AR, MA and ARMA processes, Fourier transformation and periodogram	8
8	Statistical software: R/Python	

List of Textbooks/ Reference Books

1	P. Brockwell and R. Davis, Introduction to Time Series and Forecasting, Springer, Berlin.
2	Box, G. Jenkins and G. Reinsel, Time Series Analysis-Forecasting and Control, 3rd ed., Pearson Education.
3	W. A. Fuller, Introduction to Statistical Time Series.
4	Ruey S. Tsay, An Introduction to Analysis of Financial Data with R, John Wiley.
5	T. W. Anderson, The Statistical Analysis of Time Series.
6	R. H. Shumway and D. S. Stoffer, Time Series Analysis and Its Applications.
7	C. Chatfield, The Analysis of Time Series – An Introduction, Chapman and Hall / CRC, 4th ed.

Course Outcomes (students will be able to…..)

CO1	apply graphical techniques to descriptive exploration of time series data.	
CO2	understand different statistical properties of stationary time series models and apply them in analysing real data.	
CO3	apply different forecasting techniques for time series data.	
CO4	apply state space models in forecasting problems.	
CO5	compute spectral density functions for different time series models.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	0	5	5	3	0	3	0	5	0	0	5
CO2	0	0	5	5	4	3	4	0	5	3	0	5
CO3	0	1	5	5	3	2	3	0	5	1	0	5
CO4	0	1	5	5	4	2	5	5	5	0	3	5
CO5	0	1	5	5	3	1	5	5	5	4	3	5

	Course Code: MAT 2647	**Course Title: Operator Theory**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV (Elective – III)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Applied Linear Algebra (MAT 2201), Real Analysis-I (MAT 2202), Real Analysis – II (MAT 2207), Functional Analysis (MAT 2210)		
List of Courses where this course will be prerequisite		
Not Applicable		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
	Course Contents (Topics and subtopics)	**Hours**
1	Adjoints of bounded operators on a Hilbert space, Normal, self-adjoint unitary Quasinormal, Subnormal, hyponormal operators and Normaloid	15
2	Spectrum of bounded operators and numerical ranges	10
3	Square roots of Operators and Polar Decomposition Compact operator on Hilbert spaces	10
4	Spectral theorem for compact self-adjoint operators, Singular value decomposition	10
5	Hilbert Schmidth and Trace Class operators, Application to Sturm-Liouville Problems.	15
	List of Textbooks/ Reference Books	
1	B.V. Limaye, Functional Analysis, 2nd Edition,New Age International.	
2	J. B. Conway, A Course in Functional Analysis, 2nd Edition, Springer.	
3	Carlos Kubrusly, Elements of Operator Theory, Birkhauser.	
4	Kreyzig, Introduction to Functional Analysis with Applications, John Wiley & Sons.	
5	S. G. Mikhlin, Variation Methods in Mathe-matical Physics, Pergaman Press, Oxford.	
	Course Outcomes (students will be able to…..)	
CO1	identify various operators on Hilbert spaces.	
CO2	compute spectrum of operators.	
CO3	understand the spectral theorem of compact operators and apply it to prove the singular value decomposition.	
CO4	apply the theory to Sturm Liouville boundary value problems.	
CO5	see the analogy between polar representation of complex numbers and operators.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	5	3	2	0	4	1	0	0	5	0	0	5
CO2	5	3	0	0	5	0	2	0	5	2	0	5
CO3	5	0	3	3	5	0	1	0	5	0	0	5
CO4	5	0	0	0	4	2	2	0	5	0	0	5
CO5	5	0	1	0	4	2	0	1	5	0	0	5

	Course Code: MAT 2648	**Course Title: Bayesian Statistics**	**Credits = 4**		
			L	**T**	**P**
	Semester: IV (Elective – III)	**Total contact hours: 60**	**3**	**1**	**0**

List of Prerequisite Courses		
Probability Theory (MAT 2321), Statistical Inference (MAT 2322), Statistical Computing (MAT 2323)		
List of Courses where this course will be prerequisite		
Description of relevance of this course in the M.Sc. Engineering Mathematics Program		
This course gives the students an exposure to in depth understanding of Bayesian computations which play very important role in scientific computations.		

	Course Contents (Topics and subtopics)	**Hours**
1	Basics of minimaxity, subjective and frequentist probability, Bayesian inference, prior distributions, posterior distribution, loss function, principle of minimum expected posterior loss, quadratic and other common loss functions, advantages of being a Bayesian. Improper priors, common problems of Bayesian inference, Point estimators, Bayesian HPD confidence intervals, testing, credible intervals, prediction of a future observation.	15
2	Large sample properties, Consistency and asymptotic normality of posterior distribution, Laplace's method.	12
3	Bayesian Computations: Analytic approximation, E-M Algorithm, Monte Carlo sampling, Markov Chain Monte Carlo Methods, Metropolis-Hastings Algorithm, Gibbs's sampling, examples, convergence issues.	18
4	Bayesian Linear models, linear regression, generalized linear models, JAGS	15
5	Software: R or Python	

	List of Textbooks/ Reference Books
1	Bolstad, W. M. Introduction to Bayesian Statistics, 2nd Edn. Wiley.
2	Christensen R, Johnson, W., Branscum, A. and Hanson T. E. Bayesian Ideas and Data Analysis: An Introduction for Scientists and Statisticians, Chapman & Hall.
3	Congdon, P. Bayesian Statistical Modeling, Wiley.
4	Jim, A. Bayesian Computation with R, 2nd Edn, Springer.
5	Rao. C. R. and Day. D. Bayesian Thinking, Modeling & Computation, Handbook of Statistics, Vol. 25. Elsevier.
6	Jayanta K. Ghosh, Mohan Delampady, Tapas Samanta, An Introduction to Bayesian Analysis, Theory and Methods.
7	Richard McElreath, Statistical Rethinking.

	Course Outcomes (students will be able to…..)	
CO1	understand basics of Bayesian inference and its application to real data.	
CO2	compare the efficiency of Bayesian estimators with maximum likelihood estimators.	
CO3	apply different methods to simulate samples from the posterior distributions.	
CO4	make prediction of future observations using Bayesian methods.	
CO5	understand and derive the asymptotic distribution of Bayes estimators.	

Mapping of Course Outcomes (COs) with Programme Outcomes (POs)												
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	0	0	5	5	3	0	3	0	5	1	0	5
CO2	0	0	5	5	4	3	4	0	5	3	0	5
CO3	0	0	5	5	3	0	3	0	5	0	0	5
CO4	0	0	5	5	4	0	5	5	5	0	3	5
CO5	0	0	5	5	3	2	5	5	5	4	3	5