Department of Mathematics & Computing, IIT (ISM) Dhanbad

Course Structure for Ph. D programme (W.E.F: Academic Year 2021 – 2022)

First Semester							
Sl. No	**Designation**	**Course No**	**Course Name**	**L**	**T**	**P**	**C**
1	DC-1	MCC500	Research Methodology	3	0	0	9
2	DC-2	MCC501	Analysis	3	0	0	9
3	DC-3	MCC502	Differential Equations	3	0	0	9
4	DC-4	MCC503	Numerical Methods	3	0	0	9
5	IC	HSI500	Research and Technical Communication	3	0	0	S/X
			Total	15	0	0	36

Second Semester							
Sl. No	**Designation**	**Course No**	**Course Name**	**L**	**T**	**P**	**C**
1	DE-1	######	Any four/two DE out of Table 1, Any two OE out of Table 2.	3	0	0	9
2	DE-2	######		3	0	0	9
3	DE-3 / OE-1	######		3	0	0	9
4	DE-4 / OE-2	######		3	0	0	9
			Total	12	0	0	36
Note: 1. ###### indicates the course numbers from the list of Departmental Elective (DE) / Open Elective (OE) papers.							

Third Semester					
Course Code	**Subject Name**	**L**	**T**	**P**	**C**
MCC599	Thesis Unit	0	0	0	36

Fourth Semester					
Course Code	**Subject Name**	**L**	**T**	**P**	**C**
MCC599	Thesis Unit	0	0	0	36

Fifth Semester					
Course Code	**Subject Name**	**L**	**T**	**P**	**C**
MCC599	Thesis Unit	0	0	0	36

Sixth Semester					
Course Code	**Subject Name**	**L**	**T**	**P**	**C**
MCC599	Thesis Unit	0	0	0	36

Seventh Semester					
Course Code	**Subject Name**	**L**	**T**	**P**	**C**
MCC599	Thesis Unit	0	0	0	36

Eighth Semester					
Course Code	**Subject Name**	**L**	**T**	**P**	**C**
MCC599	Thesis Unit	0	0	0	36

Departmental Elective Papers

Sl. No	Course No	Course Name	L	T	P	C
1	MCD551	Advanced Analysis	3	0	0	9
2	MCD552	Advanced Numerical Methods	3	0	0	9
3	MCD553	Modelling and Simulation	3	0	0	9
4	MCD554	Advance Sampling Theory- I	3	0	0	9
5	MCD555	Advance Sampling Theory- II	3	0	0	9
6	MCD556	Algebraic Number Theory	3	0	0	9
7	MCD557	Finite Field Theory	3	0	0	9
8	MCD558	Wavelets: Theory and Applications	3	0	0	9
9	MCD559	Celestial Mechanics	3	0	0	9

10	MCD560	Orbital Mechanics	3	0	0	9
11	MCD561	Analytical Number Theory	3	0	0	9
12	MCD562	Decision Theory	3	0	0	9
13	MCD563	Finite Element Analysis	3	0	0	9
14	MCD564	Fuzzy Set Theory and its Applications	3	0	0	9
15	MCD565	Multigrid Methods	3	0	0	9
16	MCD566	Software Reliability	3	0	0	9
17	MCD 567	Algorithmic Graph Theory	3	0	0	9
18	MCD568	Coding Theory	3	0	0	9
19	MCD569	Advance Optimization Techniques	3	0	0	9
20	MCD570	Nonlinear Programming	3	0	0	9
21	MCD571	Hydrodynamics & Application to Groundwater	3	0	0	9
22	MCD572	Dynamical Systems: Theory and Applications	3	0	0	9
23	MCD573	Mathematical Biology	3	0	0	9
24	MCD574	Statistical Reliability Theory	3	0	0	9

Open Elective Papers

Sl. No	Course No	Course Name	L	T	P	C
1	MCO501	Discrete Mathematics	3	0	0	9
2	MCO531	Stochastic Processes	3	0	0	9
3	MCO532	Advanced Multivariate Analysis	3	0	0	9
4	MCO533	Numerical Linear Algebra	3	0	0	9

Table 1: List of Departmental Elective Papers

Sl. No	Designation	Course No	Course Name	L	T	P	C
1	DE-1	MCD551	Advanced Analysis	3	0	0	9
2		MCD552	Advanced Numerical Methods	3	0	0	9
3		MCD554	Advance Sampling Theory- I	3	0	0	9
4		MCD561	Analytical Number Theory	3	0	0	9

5		MCD 567	Algorithmic Graph Theory	3	0	0	9
6		MCD569	Advance Optimization Techniques	3	0	0	9
7		MCD572	Dynamical Systems: Theory and Applications	3	0	0	9
8	DE-2	MCD553	Modelling and Simulation	3	0	0	9
9		MCD555	Advance Sampling Theory- II	3	0	0	9
10		MCD556	Algebraic Number Theory	3	0	0	9
11		MCD566	Software Reliability	3	0	0	9
12		MCD573	Mathematical Biology	3	0	0	9
13	DE-3	MCD557	Finite Field Theory	3	0	0	9
14		MCD559	Celestial Mechanics	3	0	0	9
15		MCD565	Multigrid Methods	3	0	0	9
16		MCD568	Coding Theory	3	0	0	9
17		MCD570	Nonlinear Programming	3	0	0	9
18		MCD574	Statistical Reliability Theory	3	0	0	9
19	DE-4	MCD558	Wavelets: Theory and Applications	3	0	0	9
20		MCD560	Orbital Mechanics	3	0	0	9
21		MCD562	Decision Theory	3	0	0	9
22		MCD563	Finite Element Analysis	3	0	0	9
23		MCD564	Fuzzy Set Theory and its Applications	3	0	0	9
24		MCD571	Hydrodynamics & Application to Groundwater	3	0	0	9

***** Any four out of this list or from Departmental Electives (2 Year M.Sc (M&C) / 2 Year M.Tech (Data Analytics)) or from other Departments may be opted subject to the offered by Departments.

Table 2: List of Open Electives Papers

Sl. No	Designation	Course No	Course Name	L	T	P	C
1	OE-1	MCO531	Stochastic Processes	3	0	0	9
2		MCO532	Advanced Multivariate Analysis	3	0	0	9
3	OE-2	MCO533	Numerical Linear Algebra	3	0	0	9
4		MCO501	Discrete Mathematics	3	0	0	9

MCC500 **Research Methodology** **L-T-P: 3-0-0**

Objective: To give the idea about formulation of research problems, exposure of basic statistical techniques, use of computational tools/softwares and scientific writings.

Outcome: Students will be equipped with the knowledge of how to start the systematic research in their chosen area and will be able to accomplish their work up to the satisfaction of all concerned.

Course Content	**Unit 1** **7 Lectures** **Research Plan and Methodology:** Overview, Conceptualization and Formulation of Research Problems, Review of Literature, Evaluation of Research and Research Ethics. **Unit II** **9 Lectures** **Computational Tools and Techniques:** Fundamentals, Programming Skills and Scientific Software, Presentation tools, Web Search Tools. **Unit III** **15 Lectures** **Advanced Mathematical, Statistical Tools and Techniques:** Analytical and Numerical Techniques, Statistical Techniques and Data Analysis, Graphical Representation of Quantitative Data, Concept of Error Analysis. **Unit IV** **8 Lectures** **Technical Scientific Writing:** Research Papers, Thesis, Report, Monograph and other Scientific Documents etc.
Learning Outcome	**Unit I:** Gives the idea about formulation of research problems, review of articles/papers and how to maintain research ethics. **Unit II:** Gives the idea about fundamentals of programming skills and uses of soft wares. **Unit III:** Gives the idea about mathematical and statistical tools applicable in data analysis. **Unit IV:** Gives the idea about writing skills of research papers, thesis, monographs and other research articles.
Text Books	1. Kothari C.K., Research Methodology – Methods and Techniques. New Age International, New Delhi, 2004 2. Peter Pruzan, Research Methodology: The Aims, Practices and Ethics of Science. Springer, 2016
Reference Books	1. Michael P. Marder, Research Methods for Science. Cambridge University Press, 2011 2. Hilary Glasman-Deal, Science Research Writing for Non-native Speakers of English. World Scientific, 2010.

MCC501 **Analysis** **L-T-P: 3-0-0**

Prerequisite: Real Analysis (Functions of one variable: Limit, Continuity, Differentiability and Riemann Integral) and Linear Algebra.

Objective: **1.** To introduce Calculus in several variables (concept of Limit, Continuity, Differentiability in several variables). **2.** To introduce the basics of Riemann Stieltjes and Lebesgue integrals.

Outcome: The students will be able to understand (i) the basic idea of Limit, Continuity, and Differentiability in several variables and its applications in Geometry (ii) the basics of Lebesgue integrals which extends the integral to a larger class of functions and also extends the domains on which these functions can be defined.

Course Content	**Unit I** **12 Lectures** Functions of two or three variables, Limit, Continuity, Differentiability, Directional derivatives, Partial derivatives, Total derivative, Gradient, Tangent Plane, Mixed derivative Theorem, Mean value Theorem, Extended Mean value Theorem, Taylor’s Theorem, Chain Rule, Maxima and minima, Saddle point, Method of Lagrange's multipliers. **Unit II** **9 Lectures** Functions of several variables: Differentiation, derivative as a linear Transformation, Jacobians, Contraction mapping principle, Inverse and Implicit function theorems. **Unit III** **9 Lectures** Review of Riemann integral, Riemann Stieltjes integral, existence and its properties, Improper integrals. **Unit IV** **9 Lectures** Lebesgue measure, Measurable functions, Lebesgue integral.
Learning Outcome	**Unit I:** This unit will help students to understand the concept of limit and continuity in several variables and to get Taylors expansion. Students will also learn to find maxima and minima of a function. **Unit II:** Students will be able to understand differentiation in several variables and their applications. **Unit III:** Students will get the idea of Riemann Stieltjes integral and Improper integrals. **Unit IV:** Students will learn the basics of Lebesgue integrals
Text Books	**1.** T. M. Apostol, Mathematical Analysis, 2nd Edition, Narosa, 2002. **2 .**H.L. Royden, Real Analysis, 4th Edition, Prentice Hall India, 2011.
Reference Books	**1.** S. R. Ghorpade and B. V. Limaye, A Course in Multivariable Calculus and Analysis, Springer, 2010. **2**. T. M. Apostol, Calculus, Volume 2, 2nd Edition, Wiley, 2007. **3.** W. Rudin, Principles of Mathematical Analysis, 3rd Edition, McGraw-Hill, 2017. **4.** I. K. Rana, An Introduction to Measure and Integration, 2nd Edition, Narosa, 2004.

MCC502 **Differential Equations** **L-T-P: 3-0-0**

Prerequisite: Real analysis, Fourier series, Elementary topics of differential equations**.**
Objective: To understand the theory of ordinary and partial differential equations and their utility in solving real-world problems arising in mathematical physics and engineering.
Outcome: Students will get expertize to solve problems in mathematical physics and engineering.

Course Content	**Unit I** **5 Lectures** Initial value problems, Existence and uniqueness and continuity theorems, Series solution around an ordinary point and a regular singular point, the method of Frobenius. **Unit II** **7 Lectures** Bessel differential equation, Bessel functions properties, Generating function, Legendre differential equation, Legendre function, Orthogonal property of Legendre polynomials, Generating function. **Unit III** **7 Lectures** Two-point boundary value problems, Green's functions, Self-adjoint Eigen value problems, Sturm-Liouville systems. **Unit IV** **13 Lectures** Linear and Quasi linear equations, Partial Differential Equations of second order with constant and variable coefficients, Classification and reduction of second order equations to canonical form, Cauchy, Neumann and Dirichlet problems. **Unit V** **7 Lectures** Solution of Laplace, wave and unsteady heat equations by variable-separable method, solution of wave and unsteady heat equations innon-homogeneous cases
Learning Outcome	**Unit I:** From this topic, student will understand the criteria for the existence and uniqueness of solutions of differential equations. In addition, student will learn an efficient technique to solve equations with variable coefficients. **Unit II:** From this topic, student will understand the theory of some special functions which often occur when solving physical problems **Unit III:** From this topic, student will understand about boundary value problems and widely used Green's function technique. In addition to this, student will knowledge on eigen-value problems which often occur in solving model equations. **Unit IV:** From this topic, student will get the knowledge on the genesis of partial differential equations. Moreover, it helps to understand various types of boundary value problems based on physical assumptions. **Unit V:** From this topic, student will learn several methods to solve partial differential equations.
Text Books	1.T. Myint-U, Ordinary Differential Equations, North-Holland, New York (1978). 2.T. Amaranath, An Elementary Course in Partial Differential Equations, 2nd Ed. Narosa Publishing House, Chennai (2002).
Reference Books	1.G. F. Simmons, Differential Equations with Applications and Historical Notes, Tata McGraw-Hill Edition, Delhi (2003). 2.W.W. Bell**,** Special Functions for Scientists and Engineers, Van Nostrand Ltd. (1968).

MCC503 **Numerical Methods** **L-T-P: 3-0-0**

Objective: Due to immense development in the computational technology, numerical methods are more popular as a tool for scientists and engineers. This branch of Mathematics dealt with to find approximation solution of difficult problems such as finding roots of non-linear equations, numerical integration, numerical solutions of the ordinary differential equations and partial differential equations with initial or boundary conditions.

Outcome: It is expected that students will learn many methods to solve mathematical model with real data and also enhance their application skills

Course Content	**Unit I** **12 Lectures** Solution of tridiagonal system, Solution of simultaneous non-linear equations, Central Difference interpolation formulae, Numerical evaluation of double and triple integrals with constant and variable limits and its application, Solution of integral equations, Solution of initial-value problem by single and multistep methods **Unit II** **10 Lectures** Solution of linear and non-linear boundary-value problems, Solution of Characteristics value problems, Solution of Laplace and Poisson equations in two variables by five point formula, Solution of Laplace equation in two variables by ADI method, Solution of mixed boundary value problem **Unit III** **8 Lectures** Algorithm for elliptic equation in three variables, Solution of parabolic partial differential equation in two variables by explicit and implicit methods, Solution of parabolic equation in three variables by ADE and ADI methods **Unit IV** **9 Lectures** Solution of hyperbolic equation in two variables by explicit and implicit methods and algorithm for hyperbolic equation in three variables, Stability of finite difference schemes for parabolic and hyperbolic equations.
Learning Outcome	**Unit I:** In this unit students will learn to solve tridiagonal system, non-linear equations and integral equations and interpolations formulae. **Unit II:** This unit will help students to understand the Application of boundary value problem **Unit III:** This unit will help students to apply the concept of finite difference methods to solve PDE. **Unit IV:** Students will be able to understand the stability conditions of finite difference schemes.
Text Books	1. Numerical Mathematics and Computing, by Ward Cheney and David Kincaid, International Thomson Publishing Company, (2013). 2. Analysis of Numerical Methods, by E. Isaacson & H. B. Keller, John Wiley & Sons. Dover Publications, Inc., New York, 1966
Reference Books	1. Applied Numerical Analysis, by Curtis Gerald and Patrick Wheatley, Addison-Wesley. Pearson Education India; 7 edition (2007) 2. Numerical Solution of Partial Differential Equations : Finite Difference Methods, by G. D. Smith, Oxford University Press, 1985

MCD551 **Advanced Analysis** **L-T-P: 3-0-0**

Prerequisite: Partial differential equations (two independent variables), Functional Analysis, Real Analysis (Riemann Integral) and Measure theory (Lebesgue integral).

Objective: 1. To introduce boundary value problem in higher dimension. 3. To study compact operators. 2. To introduce the basics of Multiple Riemann and Lebesgue integrals.

Outcome: The students will be able to understand (i) how to tackle boundary value problem in higher dimension (ii) basics of compact operators and its properties (ii) the basics of multiple Riemann and Lebesgue integrals.

Course Content	**Unit** **11 Lectures** Introduction to Boundary-Value Problems: Partial Differential Operators on $\mathbb{R}^n$, Laplacian in $\mathbb{R}^n$, Separation of Variables: Heat, Laplace and Wave equations, Sturm–Liouville Theory: Eigenvalue and Eigenfunction of the differential operator, Green's formula, Sturm–Liouville eigenvalue problem, Sturm's Theorem, Green's function, special case of Hilbert–Schmidt theorem. **Unit II** **11 Lectures** Compact Self-Adjoint Operators: Compact Operators, Spectral Theorem for Compact Self-Adjoint Operators, Hilbert–Schmidt Theorem, Unitary Operators, Classes of Compact Operators. **Unit III** **08 Lectures** Multiple Riemann Integrals: The measure of a bounded interval in $\mathbb{R}^n$, The Riemann integral of a bounded function defined on a compact interval in $\mathbb{R}^n$, Sets of measure zero and Lebesgue's criterion for existence of a multiple Riemann integral, Evaluation of a multiple integral by iterated integration, Jordan-measurable sets in $\mathbb{R}^n$, Jordan content expressed as a Riemann integral, Mean-Value Theorem for multiple integrals. **Unit IV** **09 Lectures** Multiple Lebesgue Integrals, Step functions and their integrals, Upper functions and Lebesgue-integrable functions, Measurable functions and measurable sets in $\mathbb{R}^n$, Fubini's reduction theorem for the double integral of a step function, Some properties of sets of measure zero, Fubini's reduction theorem for double integrals.
Learning Outcome	**Unit I:** Students will learn to solve boundary value problems in higher dimension and also the basics of Green functions. **Unit II:** Students will learn the theory of Compact Self-Adjoint Operators and its applications. **Unit III:** Student will able to understand Multiple Riemann Integrals. **Unit IV:** Student will able to understand Multiple Lebesgue Integrals.
Text Books	1. A. W. Knapp, Advanced Real Analysis, Digital Second Edition, Birkh¨auser, 2017. 2. W.Rudin, Functional Analysis, International series in pure and applied Mathematics, Tata-McGraw Hill edition, 2007.
Reference Books	1. S. David Promislow, A first course in Functional Analysis, Pure and applied Mathematics, Wiley-Interscience, 2008. 2. T. M. Apostol, Mathematical Analysis, 2nd Edition, Narosa, 2002.

MCD552 **Advanced Numerical Methods** **L-T-P: 3-0-0**

Objective: Computational technology, numerical methods are more popular as a tool for scientists and engineers. This branch of Mathematics dealt with to find approximation solution of difficult problems such as finding roots of non-linear equations, numerical integration, numerical solutions of the ordinary differential equations and partial differential equations with initial or boundary conditions.

Outcome: It is expected that students will learn many methods to solve mathematical model with real data and also enhance their application skills.

Course Content	**Unit-I** **9 Lectures** Solution of Tridiagonal systems, Solution of simultaneous nonlinear algebraic and transcendental equations, Central difference interpolation. **Unit-II** **9 Lectures** Numerical evaluation for double and triple integrals. Solution of integral equations by numerical methods. Numerical solution of initial value problems. Numerical solution of linear and nonlinear boundary value problems. **Unit-III** **11 Lectures** Numerical solution of elliptic partial differential equations: Solution of Laplace and Poisson equations, Solution of mixed boundary value problems, Solution of parabolic partial differential equations: Solution of heat conduction equations in two variables by explicit and implicit methods. **Unit-IV** **10 Lectures** Solution of heat conduction equations in three variables by ADE and ADI methods, Solution of hyperbolic partial differential equations: Solution of wave equation in two variables by explicit and implicit methods.
Learning Outcome	**Unit I:** In this unit students will learn to solve tridiagonal system, non-linear equations and interpolations formulae. **Unit II:** This unit will help students to understand the Application of of integral equations and initial value problem. **Unit III:** This unit will help students to understand the Application of boundary value problem. **Unit IV:** This unit will help students to understand the Application of boundary value problem.
Text Books	1. Numerical Mathematics and Computing, by Ward Cheney and David Kincaid, International Thomson Publishing Company, 2013. 2. Applied Numerical Analysis, by Curtis Gerald and Patrick Wheatley, Addison-Wesley. Pearson Education India; 7 edition 2007
Reference Books	1. Analysis of Numerical Methods, by E. Isaacson & H. B. Keller, John Wiley & Sons. Dover Publications, Inc., New York, 1966 2. Numerical Solution of Partial Differential Equations: Finite Difference Methods, by G. D. Smith, Oxford University Press, 1985.

MCD553 **Modelling and Simulation** **L-T-P: 3-0-0**

Objective: 1. To understand the basics of models and modeling. 2. To apply Mathematical Modeling concepts to understand the real life problem and its solutions.

Outcome: 1. To apply Mathematical Modeling concepts to understand the real life problem and its solutions. **2.** It also provides idea of analyzing the different continuous and discrete model systems. **3.** It helps students in understanding the concept of virus dynamics and its application in the formulation of the models related to epidemic and eco-epidemic systems. **4.** It helps students in understanding the formulation and analysis of different models related to Physical, atmospheric and mining systems. **5**. It helps to understand the formulation and analysis of different types of models in Engineering and Neural systems. **6.** Also helps to understand the dynamics by performing the simulations.

Course Content	**Unit I** **11 Lectures** Deterministic and stochastic models, Continuous and Discrete models, Formulations, Characteristics, Classifications, tools, techniques, modeling approaches, Modeling diagram. Compartmental models, Dynamical systems and its mathematical models. **Unit II** **9 Lectures** Models from systems of natural sciences: single and interacting populations, prey-predator, competition, Epidemic models and its Virus dynamics, Eco-epidemic models. Spatial and spatiotemporal Models related models with natural sciences, epidemic and eco-epidemic models. **Unit III** **9 Lectures** Modeling of physical, Atmospheric and mining systems: Models of Heating and Cooling, Henon-Heiles System, Models for traffic flow, Models for vehicle dynamics, Lorenz's model for global atmospheric circulation, Model for detecting land mines, Crimes model. Arm race models, models of Love affairs. **Unit IV** **10 Lectures** Modeling Engineering and Neural systems: Models from Mechanical and Electronics systems. Hunt's oscillator, Neural models of single neuron, Models with delay and fractional order dynamics, Matlab programs to study the dynamics of the developed model systems.
Learning Outcome	**Unit I:** To apply Mathematical Modeling concepts to understand the real life problem and its solutions. **Unit II:** It helps students in understanding the concept of virus dynamics and its application in the formulation of the models related to epidemic and eco-epidemic systems. **Unit III:** It helps students in understanding the formulation and analysis of different models related to Physical, atmospheric and mining systems. **Unit IV:** It helps to understand the formulation and analysis of different types of models in Engineering and Neural systems. Also helps to understand the dynamics by performing the simulations.
Text Books	1. R.K. Upadhyay, S.R.K. Iyengar, Introduction to mathematical modeling and chaotic dynamics. Chapman and Hall/CRC, 2013. 2. S. Banerjee, Mathematical Modeling: Models, Analysis and Applications, 2004.
Reference Books	1. E. Allman, J.A. Rhodes, Mathematical models in Biology: An introduction. Cambridge University Press 2004. 2. W. Gerstner, W.M. Kistler, R. Naud. L. Paninski, Neuronal Dynamics. Cambridge University Press2014.

MCD554 **Advance Sampling Theory- I** **L-T-P: 3-0-0**

Objective: To give the exposure of advance sampling techniques applicable in latest research.
Outcome: Students will be capable in handling the research problems in more calibrated way.

Course Content	**Unit I** **5 lectures** Concept of sampling design, frame and strategies, fixed population versus super population approach. **Unit II** **9 lectures** Sampling with varying probabilities. Probability proportional to size sampling. Horvitz-Thompson estimator, Ordered and Unordered estimators, Midzuno system of sampling. **Unit III** **9 lectures** Use of Auxiliary information at estimation stage. Study of ratio and product estimator under super population model, Factor-type estimator, Dual to ratio estimator, Chain- type estimators in two-phase sampling. **Unit IV** **8 lectures** Construction of unbiased estimators: Interpenetrating sub-samples and jack-knife techniques. **Unit V** **8 lectures** Successive sampling, Estimation of population median, Estimation of population variance.
Learning Outcome	**Unit I:** Gives the idea about fundamentals and different approaches of survey sampling. **Unit II:** Gives the idea about advanced sampling schemes and important estimators. **Unit III:** Gives the elaborative methods for using the auxiliary information at estimation stage in survey sampling. **Unit IV:** Gives the idea about the methods of constructing unbiased estimators in survey sampling. **Unit V:** Provides the concept of successive sampling and introduces some natural estimators.
Text Books	1. W. G. Cochran, Sampling Techniques, 3rd Ed, Wiley Eastern Ltd. 2. P. V. Sukhatme, B.V. Sukhatme, S. Sukhatme, and C. Ashok, Sampling Theory of Surveys with Applications, IASRI New Delhi, 1984 Ed.
Reference Books	1. M. N. Murthy, Sampling Theory and Methods, Statistical Publishing Society, Calcutta. 2. Sarjinder Singh, Advanced Sampling – Theory with Applications, Kluwer Publications. 3. Desraj and P. Chandhok, Sampling Theory, Narosa Publications, New Delhi. 4. Parimal Mukhopadhyay, Theory and Methods of Survey Sampling, 2nd Ed, PHI Learning Pvt. Limited, Delhi.

MCD555 **Advance Sampling Theory- II** **L-T-P: 3-0-0**

Objective: To give the exposure of latest sampling techniques to handle the missing data problems in survey research.
Outcome: Students will be equipped with the knowledge to mitigate the negative effect of missing data at the estimation stage in survey sampling.

Course Content	**Unit I** **6 lectures** Sampling and Non-sampling errors, Non-sampling errors: Measurement error, Non-response, Specification error, coverage error. **Unit II** **11 lectures** Types of missing data: Missing At Random (MR), Missing Completely at Random (MCAR), Observed at Random(OAR), Parameter Distinctness (PD); Imputation methods: Mean, Ratio and regression methods of Imputation, Multiple imputation method. **Unit III:** **6 lectures** Hansen Hurwitz technique, Estimation procedure of population mean using Hansen Hurwitz technique. **Unit IV:** **10 lectures** Sensitive characteristics, Randomized response techniques: Warner's method, Simmons unrelated question randomized response method for qualitative and quantitative characteristics, Two-stage randomized response method. **Unit V** **6 lectures** Measurement errors during survey, Estimation procedure under measurement errors.
Learning Outcome	**Unit I:** Provides the details about errors arise in sample surveys. **Unit II:** Gives the idea about missing patterns of data in survey sampling and methods to tackle it by imputation **Unit III:** Gives the idea to handle the problems of non-response through sub sampling techniques of non-respondents. **Unit IV:** Gives the idea about handling the problems of non-response arise due to sensitive nature of characteristics. **Unit V:** Gives the idea about handling the observational/measurement errors in survey sampling.
Text Books	1. Sarjinder Singh, Advanced Sampling – Theory with Applications, Kluwer Publications. 2. D. B. Rubin, Multiple imputation for nonresponse in surveys, Wiley Series in Probability and Statistics.
Reference Books	1. D. B. Rubin, Inference and missing data, Biometrica, **63**, 581-593, 1976 2. R. J. A Little and D. B. Rubin, Statistical Analysis with Missing Data, Wiley Series in Probability and Statistics. 3. A. Chaudhuri, and R. Mukerjee, Randomized Response: Theory and Techniques, CRC Press Inc, Taylor & Francis Inc, United States.

MCD556 **Algebraic Number Theory** **L-T-P: 3-0-0**

Prerequisite: Algebra (basic Field theory and Ring Theory)

Objective: To study algebraic number fields, its properties and applications in details.

Outcome: Students will be able to understand different properties and applications of number fields.

Course Content	**Unit I** **6 Lectures** Algebraic number fields. Localisation, discrete valuation rings. **Unit II** **7 Lectures** Integral ring extensions, Dedekind domains, unique factorisation of ideals. Action of the Galois group on prime ideals. **Unit III** **11 Lectures** Valuations and completions of number fields, discussion of Ostrowski's theorem, Hensel's lemma, unramified, totally ramified and tamely ramified extensions of p-adic fields. **Unit IV** **9 Lectures** Discriminants and Ramification. Cyclotomic fields, Gauss sums, quadratic reciprocity. **Unit V** **6 Lectures** The ideal class group, finiteness of the ideal class group, Dirichlet units theorem.
Learning Outcome	**Unit I:** Student will able to understand the properties of algebraic number fields. **Unit II:** This unit help students to understand ring extensions, Dedekind domains and action of Galois groups. **Unit III:** Students will learn about the completions and different types of ramified extensions. **Unit IV:** Students will learn the discriminants, different properties of Cyclotomic fields and law of reciprocity. **Unit V:** This unit help to students to understand the proofs of finiteness of the ideal class group, Dirichlet units theorem.
Text Books	1. K. Ireland and M. Rosen, A Classical Introduction to Modern Number Theory, 2nd Edition, Springer, 1998. 2. S. Lang, Algebraic Number Theory, 2nd Edition, Springer, 2000.
Reference Books	1. D. A. Marcus, Number Fields, Springer, 2018. 2. J. Neukirch, Algebraic Number Theory, Springer-Verlag, 1999.

MCD557 **Finite Field Theory** **L-T-P: 3-0-0**

Prerequisite: Group Theory and ring theory

Objective: Finite Field theory plays an important role in the Computer science and Electrical Communications as well as in mathematics itself. Consequently, it becomes more and more desirable to introduce the student to the field theory at an early stage of study

Outcome: Finite Filed Theory is an abstract branch of mathematics that originated from set theory. The main outcome of this course is to develop the capacity for mathematical reasoning through analyzing, proving and explaining concepts from Polynomial factorizations and Exponential sums.

Course Content	**Unit I** **9 Lectures** Review of field extensions, Characterization of finite fields, Roots of irreducible polynomials, Traces, Norms and Bases, Roots of unity, Cyclotomic polynomials, Representation of elements of finite fields, Wedderburn's theorem. **Unit II** **11 Lectures** Polynomial over finite fields: Order of polynomials, Primitive polynomials, Irreducible polynomials, Construction of Irreducible polynomials, Linearized polynomials, Binomials and Trinomials. Permutation polynomials. **Unit III** **8 Lectures** Factorization of polynomials over finite fields, Calculation of roots of polynomials, the number of solutions of the polynomial equation. **Unit IV** **11 Lectures** Exponential sums: Characters, Gaussian sums, Jacobi Sums, Character sums with polynomial arguments.
Learning Outcome	**Unit I:** The main outcome of this unit is to review the basics of finite fields, traces and norm**s.** **Unit II:** The main outcome of this unit is study the different kind of polynomials**.** **Unit III:** The main outcome of this unit is to study of factorization of polynomials over finite fields. **Unit IV:** The main outcome of this unit is to study the Gaussian sums, Jacobi Sums, Character sums with polynomial arguments.
Text Books	1. R. Lidl and H. Niederreiter, Finite Fields, Cambridge University Press, 2009. 2. G. L. Mullen and D. Panario Handbook of Finite Fields, Chapman and Hall/CRC, 2013.
Reference Books	1. A. J. Menezes, I. F. Blake, X. Gao, R. C. Mullin, S. A. Vanstone, T. Yaghoobian, Applications of Finite Fields, Springer, 1993. 2. D. Jungnickel, Finite Fields: Structure and Arithmetics, Spektrum Akademischer Verlag, 1993.

MCD558 **Wavelets: Theory and Applications** **L-T-P: 3-0-0**

Objective: Wavelets have established themselves as an important tool in modern signal processing as well as in applied mathematics. The objective of this course is to establish the theory necessary to understand and use wavelets and related constructions.

Outcome: Wavelet analysis can be defined as an alternative to the classical windowed Fourier analysis. In the latter case the goal is to measure the local frequency content of a signal, while in the wavelet case one is comparing several magnifications of this signal, with distinct resolution.

Course Content	**Unit I** **8 Lectures** Fourier analysis: Fourier and Inverse Fourier Transforms, Continuous-Time Convolution and the Delta Function, Fourier Transform of Square Integrable Functions, Fourier Series. Basic Convergence Theory and Poisson's Summation Formula. **Unit II** **8 Lectures** Wavelet Transforms and Basic Properties: The Gabor Transform. Basic Properties of Gabor Transforms. The Integral Wavelet Transforms, Dyadic Wavelets and Inversions. Basic Properties of Wavelet Transforms. **Unit III** **8 Lectures** The Discrete Wavelet Transforms. Orthonormal Wavelets, Wavelet frames & Multiband, Curvelets. Scaling Functions and Wavelets: Definition of Multiresolution Analysis and Examples. **Unit IV** **8 Lectures** Properties of Scaling Functions and Orthonormal Wavelet Bases. Construction of Orthonormal Wavelets. **Unit V** **7 Lectures** Daubechie's Wavelets and Algorithms.
Learning Outcome	**Unit I:** To study Fourier transforms, Fourier series and their basic properties. **Unit II:** To study wavelets and wavelet transforms with examples. The basic ideas and properties of wavelet transforms are discussed with special attention given to the use of different wavelets for resolution and synthesis of signals. **Unit III:** In this unit the orthonormal wavelet transform is implemented in the multiresolution signal analysis framework, which is based on the scaling functions. **Unit IV:** To study the concept of scaling functions and orthonormal wavelet bases. This is followed by a method of constructing orthonormal basis of wavelets from multiresolution signal analysis. **Unit V:** In this unit, Daubechies wavelets and algorithms has been emphasized. This unit deals with the theory and construction of orthonormal wavelets with compact support which have many interesting properties.
Text Books	1. C. K. Chui, An Introduction to Wavelets, Academic Press, New York (1992). 2. L. Debnath, Wavelet transforms and their applications, Birkhauser, Boston, MA, (2002).
Reference Books	1. I. Daubechies, Ten lectures on wavelets,In: CBMS-NSF Regional Conference Series in Applied Mathematics, SIAM Publication, Philadelphia, PA, (2006). 2. E. Hernandez and G. Weiss, A first course on wavelets, CRC Press, 1996.

MCD559 **Celestial Mechanics** **L-T-P: 3-0-0**

Objective/Outcome: 1. To learn dynamics of motions of celestial bodies
2. To understand Stability and Chaos
3. To understand Regularization and Perturbations theories

Course Content	**Unit-I** **7 Lectures** Lagrangian Dynamics, D' Alembert's Principle, Hamilton Principle, Lagrange Equations, and Hamiltonian Dynamics **Unit-II** **8 Lectures** Kepler's problem, Elliptic motion, Mean and Eccentric Anomaly, Solution of Kepler's equation,Two-Body Problem,Energy and Angular Momentum, Constants of the Motion **Unit-III** **8 Lectures** Three-Body Problem,Lagrange's solution for the motion of three bodies, Restricted Three-Body Problem, Surfaces of zero relative velocity **Unit-IV** **8 Lectures** Stability of straight line and equilateral triangle solutions, Chaos and Long Term Evolution, Sensitive Dependencies on Initial Conditions, Regular and Chaotic Orbits **Unit-V** **8 Lectures** Regularizations: Levi-Civita Regularization, Birkhoff's Regularization, Kustaanheimo-Stiefel (KS) Regularization, Theory of Perturbations: Disturbing Functions, Secular Perturbations, Resonant Perturbations.
Learning Outcome	**Unit I:** To develop strong competencies in Lagrangian Dynamics and Hamiltonian Dynamics. Be able to write down and solve Lagrange's and Hamiltonian equations. **Unit II:** To understand the foundation of the Kepler's problem and Solution of Kepler's equation. To understand Two-Body Problem and conservation laws. **Unit III:** To understand the Three-Body Problem and Lagrange's solution for Restricted Three-Body Problem(RTBP). Be able to plot the Surfaces of zero relative velocity for RTBP. **Unit IV:** To understand the concept of Stability, Chaos and Long Term Evolution. To understand method for detecting Sensitive Dependencies on Initial Conditions. **Unit V:** Be able to perform different Regularizations like Levi-Civita Regularization, Birkhoff's Regularization and Kustaanheimo-Stiefel (KS) Regularization. To understant concept of Theory of Perturbations.
Text Books	1. An Introduction to Celestial Mechanics, by Forest Ray Moulton, Courier Corporation, 2012 2. Adventures in Celestial Mechanics, by Victor G. Szebehely, Hans Mark,John Wiley & Sons, 1998
Reference Books	1. Solar System Dynamics by Carl D. Murray, Stanley F. Dermott, Cambridge University Press, 2000 2. Methods of Celestial Mechanics,Dirk Brouwer, Gerald M. Clemence,Elsevier, 2013 3. Introduction to celestial mechanics by S. W. McCuskey,Addison-Wesley, 1963

MCD560 **Orbital Mechanics** **L-T-P: 3-0-0**

Objectives/Outcome: This course aims to develop an understanding of the following topics in orbital mechanics:

1. Orbit determination and orbital transfers.
2. The use of computer programmes for the numerical analysis of orbital motion.
3. Conceptual designs of space trajectories.

Course Content	**Unit-I** **8 Lectures** The two-body problem, Circular orbits, Elliptical orbits, Parabolic orbits, Hyperbolic orbits, Universal variables,Classification of orbits with respect to the Energy constants. **Unit-II** **8 Lectures** Orbits in three dimensions:Geocentric right ascension–declination frame, State vector and the geocentric equatorial frame, Orbital elements and the state vector, Coordinate transformation, Transformation between geocentric equatorial and perifocal frames,Effects of the earth's oblateness **Unit-III** **8 Lectures** Orbit determination:Gibbs' method of orbit determination from three position vectors, Lambert's problem, Sidereal time, Topocentric coordinate system, Orbit determination from angle and range measurements, Angles-only preliminary orbit determination, Gauss's method of preliminary orbit determination **Unit-IV** **8 Lectures** Orbital Transfer and maneuvers: Impulsive maneuvers,Hohmann transfer, Bi-elliptic Hohmann transfer, Phasing maneuvers, Non-Hohmann transfers with a common apse line,Apse line rotation,Chase maneuvers, Plane change maneuvers **Unit-V** **7 Lectures** Interplanetary trajectories:Interplanetary Hohmann transfers, Rendezvous opportunities, Sphere of influence, Method of patched conics, Planetary departure, Sensitivity analysis, Planetary rendezvous, Planetary flyby, Planetary ephemeris, Non-Hohmann interplanetary trajectories Problems.
Learning Outcome	**Unit I:** Be able to understand two-body problem. To understand the concept of different type of orbits and their computation. Be able to Classify orbits with respect to the Energy constants **Unit II:** To understand the geometry of Orbits and Orbital elements. Be able to perform coordinate transformation. To know the effects of the earth's oblateness. **Unit III:** To learn the Gibbs' method and Gauss' Method of orbit determination. To understand the Lambert's problem. **Unit IV:** To perform Hohmann transfer, Bi-elliptic Hohmann transfer and Non-Hohmann transfers. To learn and can perform the Impulsive maneuvers,Phasing maneuvers, Chase maneuvers and Plane change maneuvers. **Unit IV:** Be able to understand Interplanetary trajectory design and transfer. Be able to know Sensitivity analysis, Planetary rendezvous, Planetary flyby and Planetary ephemeris.
Text Books	1. Orbital Mechanics for Engineering Students, Howard Curtis, Elsevier 2013 2. Satellite Orbits by Montenbruck, O., Gill, E., Springer, New York, 2001
Reference Books	1. Orbital Mechanics by Prussing, J.E., Conway, B.A., Oxford University Press, Inc., New York, 1993.(http://control.asu.edu/MAE462_frame.htm) 2. Orbital Motion by Roy, A.E., Institute of Physics Publishing, 1998.

MCD561 **Analytical Number Theory** **L-T-P: 3-0-0**

Prerequisite: Complex analysis.

Objective: (i) To study the different properties of prime numbers (ii) To introduce Riemann zeta functions, L-functions and modular forms and study their analytical properties.

Outcome: Students will be able to understand (i) different properties if prime numbers (ii) basics of Riemann zeta functions, L-functions and modular forms and their analytical properties.

Course Content	**Unit I** **8 Lectures** The Wiener-Ikehara Tauberian theorem, the Prime Number Theorem. Dirichlet's theorem for primes in an Arithmetic Progression. **Unit II** **8 Lectures** Zero free regions for the Riemann-zeta function and other L-functions. Euler products and the functional equations for the Riemann zeta function and Dirichlet L-functions. **Unit III** **8 Lectures** Modular forms for the full modular group, Eisenstein series, cusp forms, structure of the ring of modular forms. **Unit IV** **6 Lectures** Hecke operators and Euler product for modular forms. **Unit V** **9 Lectures** The L-function of a modular form, functional equations. Modular forms and the sums of four squares.
Learning Outcome	**Unit I:** Students will learn different properties of prime numbers. **Unit II:** Students will learn the basics of Riemann-zeta function and other L-functions and its properties. **Unit III:** Students will learn the basics of modular forms. **Unit IV:** Students will learn about Hecke operators and Euler product for modular forms. **Unit V:** Students will learn the L-function of a modular form and its properties.
Text Books	1. S. Lang, Algebraic Number Theory, 2nd Edition, Springer, 2000. 2. J.P. Serre, A Course in Arithmetic, Springer-Verlag, 1996.
Reference Books	1. T. Apostol, Introduction to Analytic Number Theory, Springer, 2010. 2. M. Overholt, A Course in Analytic Number Theory, American Mathematical Society, 2014.

MCD562 **Decision Theory** **L-T-P: 3-0-0**

Objective: To learn statistical decision problems, Bayes rules, minimax and admissible rules, invariant decision rules

Outcome: 1. The student will familiarize with fundamental concepts of the statistical decision theory.

2. Students will be able to derive optimal decision rules for several problems using decision theoretic approach.

Course Content	**Unit I** **9 Lectures** Games and statistical games, statistical decision problem, decision function, risk function, Randomized and non-randomized decision rules, prior and posterior distribution, Bayes risk and Bayes rules, least favourable prior **Unit II** **9 Lectures** Minimaxity, admissibility and complete classes, admissibility of Bayes rules, existence of minimal complete class and Bayes rules, the supporting and separating hyperplane theorems **Unit III** **10 Lectures** Essential completeness of the class of nonrandomized rules, Minimax and complete class theorems, solving for minimax rules **Unit IV** **11 Lectures** Essential completeness of class of rules based on sufficient statistics, continuity of risk functions, Invariant decision problems, admissible and minimax invariant decision rules, Location parameter problems, Confidence and credible sets.
Learning Outcome	**Unit I:** The student will familiarize with fundamental concepts of the statistical decision theory. **Unit II:** Different optimal properties of the decision rules and related theories. **Unit III:** The student will understand the theory of minimaxity and completeness. **Unit IV:** Students will be able to derive optimal decision rules for several problems using decision theoretic approach
Text Books	1. T. S. Ferguson (2014), Mathematical Statistics: A Decision Theoretic Approach, Academic Press
Reference Books	1. J. O. Berger (1985). Statistical Decision Theory and Bayesian Analysis, 2nd Ed. Springer, New York 2. H. Raiffa and R. Schlaifer (2000). Applied Statistical Decision Theory, Wiley-Interscience.

MCD563 **Finite Element Analysis** **L-T-P: 3-0-0**

Prerequisite: A first course in numerical solutions of differential equations. Knowledge of variational calculus is advantageous but not necessary.

Objective: Finite element analysis is the study of a versatile numerical technique for solving problems arising in engineering and sciences. This first course will aim to 1. Introduce the technique, 2. Teach its various aspects such as existence, uniqueness, convergence, error estimation, and structure preservation, 3. Prepare students to use the technique to problems arising in their respective subject areas.

Outcome: After completing this course, students should demonstrate competency in the following skills: 1. Basics of Finite Element Analysis, 2. Familiarity with various aspects of the techniques and its pitfalls, 3. Various engineering and science applications of the technique.

Course Content	**Unit I** Piecewise Polynomial Approximation in 1D **Unit II** The Finite Element Method in 1D **Unit III** Piecewise Polynomial Approximation in 2D **Unit IV** The Finite Element Method in 2D **Unit V** Time-Dependent Problems	**7 Lectures** **8 Lectures** **8 Lectures** **8 Lectures** **8 Lectures**
Learning Outcome	**Unit I** Students will be reminded of interpolation, projection, and quadrature formulae **Unit II** Students will learn about various aspects of the finite element method on a 1D problem **Unit III** Students will learn about polynomial spaces, interpolation, and projections in 2D **Unit IV** Students will learn about various aspects of the finite element method on a 2D problem **Unit V** Students will learn about stability and a priori estimates of the finite element method on the heat and the wave equations.	
Text Books	1. Mats G. Larson, Fredrik Bengzon. The Finite Element Method: Theory, Implementation, and Applications, Springer Science & Business Media, 2013 2. Logan, Daryl L. A first course in the finite element method. Cengage Learning, 2011.	
Reference Books	1. Lawrence C. Evans, Partial Differential Equations, American Mathematical Society. 1998	

MCD564 **Fuzzy Set Theory and its Applications** **L-T-P: 3-0-0**

Objective: To explore the foundations of mathematics used in ambiguous environment and its applications in real life.
Outcome: After the course, a student will able to model the system which can work in ambiguous environment.

Course Content	**Unit I** **11 Lectures** Basic concepts of fuzzy sets and fuzzy logic, Motivation, Fuzzy sets and their representations, Membership functions and their designing, Operations on fuzzy sets, Convex fuzzy sets, Alpha-level cuts, Geometric interpretation of fuzzy sets, *T*-norm and *T*-conorm. **Unit II** **9 Lectures** Fuzzy numbers and linguistic variables, Arithmetic operations on fuzzy numbers, Fuzzy equations, Fuzzy relations, Fuzzy equivalence relations, Composition of fuzzy relations, Fuzzy reasoning. **Unit III** **10 Lectures** Fuzzy mapping rules and fuzzy implication rules, Fuzzy rule-based models for function approximation, Types of fuzzy rule-based models (the Mamdani, TSK, and standard additive models), Introduction to fuzzy logic controller, Working of an FLC through examples, Mathematical formulation of an FLC, Real life examples. **Unit IV** **9 Lectures** Decision making in Fuzzy environment, Fuzzy Decisions, Introduction to fuzzy methods in decision making, Fuzzy Linear programming, Fuzzy Multi criteria analysis, Multiobjective decision making.
Learning Outcome	**Unit I:** To know the foundations of fuzzy set theory and operations on fuzzy sets. **Unit II:** To know the concepts of fuzzy numbers and fuzzy relations. **Unit III:** To learn the concept of fuzzy rule based systems. **Unit IV:** To learn the applications of fuzzy set theory in decision making.
Text Books	1. G.J. Klir and B. Yuan, Fuzzy Sets and Fuzzy Logic: Theory and Applications, Prentice-Hall, 1995.
Reference Books	2. T.J. Ross, Fuzzy Logic with Engineering Applications, John Wiley, 2005.

MCD565 **Multigrid Methods** **L-T-P: 3-0-0**

Prerequisite: Basics of numerical methods, algorithms, fluid dynamics is desirable.
Objective: Numerical simulations of PDEs arising from mechanics of fluid interactions.
Outcome: The student would be able to applying numerical schemes for real life systems such as CFD.

Course Content	**Unit-I** **8 Lectures** Introduction, Multigrid methods for linear systems **Unit-II** **8 Lectures** Iterative methods and smoothing property, the two grid schemes and approximations property. **Unit -III** **8 Lectures** The Two level Method, The coarse Grid problem, general approach for proving the Convergence of the two level method, smoothing property of damped Jacobi iteration. **Unit- IV** **8 Lectures** Multigrid Scheme for nonlinear problems **Unit-V** **7 Lectures** Algebraic Multigrid Methods
Learning Outcome	**Unit I:** The students will be able to familiar advanced numerical schemes rather than usual numerical schemes such as FDM, FEM etc. **Unit II:** The student will learn iterative procedure with respect to multigrid methods. **Unit III:** The student will learn higher level schemes in grid techniques. **Unit IV:** To handle more nonlinear complex real-life fluid models. **Unit-V:** Advanced techniques of multigrid.
Text Books	1. Alfio Borzi: Introduction to Multigrid Methods, Wiley.
Reference Books	2. Volker John: Multigrid methods.

MCD566 **Software Reliability** **L-T-P: 3-0-0**

Objective/Outcome: Software Reliability belongs to the broad area Software Engineering. The objective of the course to impart knowledge to the students about various concepts of Software Reliability.

Students can carry out research in the area of software reliability. Also, interested students can develop their basic knowledge of Software Engineering.

Course Content	**Unit I** **12 Lectures** Basic Concepts of Software Engineering. Concept of reliability theory: Hazard model, Series and Parallel configuration, Markov Modeling, Redundancy. System Definition: System Configuration & Test Run Selection. **Unit II** **8 Lectures** Definition of: Faults, Failures, Environment, Software Reliability, Software Repair & Software Availability. **Unit III** **10 Lectures** Software Reliability Modeling and Model Classification, Markovian Models, Calendar Time Models, Parameter Estimation, Structural Modeling **Unit IV** **3 Lectures** Comparison Techniques of Software Reliability Models **Unit V** **6 Lectures** Concept of Redundancy in Software Reliability & Cost modelling
Learning Outcome	**Unit I:** This unit will help students to understand basics of Software Engineering and Reliability Theory. **Unit II:** This unit will help students to understand different concepts of Software faults, failure, Software environment, Software Availability etc. **Unit III:** This unit will help students to understand the idea of software reliability model building under various categories. **Unit IV:** This unit will help students to understand the concept of different comparison techniques, model validation etc. **Unit V:** This unit will help students to understand Software redundancy and Software release time modelling.
Text Books	1. J.D. Musa, Anthny Iannino and Kazuhira Okumoto, Software Reliabity Measurement, Prediction and Application, McGraw-Hill, 1987.
Reference Books	1. Martin L. Shooman, Software Engineering Design, Reliability and Management, McGraw-Hill, 1983. 2. Rajib Mall, Fundamentals of Software Engineering, PHI, 2014.

MCD567 | **Algorithmic Graph Theory** | **L-T-P: 3-0-0**

Objective: **1.** To introduce the concepts of special classes of graphs. **2.** To give idea about "P vs NP" for graph optimization problems
Outcome: Ability to know the how structural characterizations of graphs help in designing efficient algorithm for graph optimization problems.

Course Content	**Unit I** **9 Lectures** Introduction to graph problems: Definition of different graph parameters such vertex cover, edge cover, longest path, maximum clique, maximum independent set, maximum matching, graph coloring, and the optimization problems associated with those. A survey on computational complexity of solving above problems for arbitrary graphs. **Unit II** **5 Lectures** Introduction to intersection graphs: Definition and structural properties, Examples. **Unit III** **9 Lectures** Interval Graphs, Chordal Graphs, Perfect Graphs: Definition and Characterization. On solving different graph problems on these classes along with NP-hard problems on these graph classes. **Unit IV** **9 Lectures** Subclasses of Bipartite Graphs: Definition and characterization of some important subclasses of bipartite graphs and solving optimization problems on these classes. **Unit V** **7 Lectures** Other classes of graphs: Split graphs, cographs, threshold graphs etc.
Learning Outcome	**Unit I:** Students will learn the basic definitions on graphs and several graph problems and also know the survey on the computational complexity of these problems. **Unit II:** This unit will help in knowing the concept of intersection graphs. **Unit III:** Students will learn how good characterizations help in solving the graph problems efficiently for several families of intersection graphs. **Unit IV:** Students will learn how good characterizations help in solving the graph problems efficiently for several families of bipartite graphs. **Unit V:** Students will learn a few other graph classes
Text Books	1. A. Brandstadt, V. B. Le and J. P. Spinrad, Graph Classes: A survey, SIAM Monograph, 1987 2. M. C. Golumbic, Algorithmic graph theory and perfect graphs, Elsevier, 2004.
Reference Books	1. J. P. Spinrad, Efficient Graph Representations, Field Institute Monograph, AMS, 2003 2. D. B. West, Introduction to Graph Theory, 2nd Edition, Phi Learning, 2009.

MCD568 **Coding Theory** **L-T-P: 3-0-0**

Prerequisite: Linear Algebra and Finite Fields

Objective: Coding Theory plays an important role in the Computer science and Electrical Communications as well as in mathematics itself. Consequently, it becomes more and more desirable to introduce the student to the Error correction codes at an early stage of study

Outcome: Coding Theory is an abstract branch of mathematics, Electrical communications and computer Science that originated from Linear Algebra. The main outcome of this course is to develop the capacity of encoding, decoding and idea of communications theory and Information theory.

Course Content	**Unit I** **08 Lectures** Binary Hamming codes, dual of a code, constructing codes by various operations, simplex codes, Hadamard matrices and codes constructed from Hadamard and conference matrices, Plotkin bound and various other bounds, Gilbert-Varshamov bound. **Unit II** **08 Lectures** Reed-Muller and related codes: First order Reed-Muller codes, RM code of order r, Decoding and Encoding using the algebra of finite field with characteristic two. Perfect codes. **Unit III** **08 Lectures** Weight enumerators, Kratchouwk polynomials, Lloyd theorem, Binary and ternary Golay codes, connections with Steiner systems.Cyclic codes: The generator and the check polynomial, zeros of a cyclic code, the idempotent generators, BCH codes, Reed-Solomon codes, Quadratic residue codes, generalized RM codes. **Unit IV** **15 Lectures** Codes over Z4: Quaternary codes over Z4, binary codes derived from such codes, Galois rings over Z4, cyclic codes over Z4. Goppa codes: the minimum distance of Goppa codes, generalized BCH codes, decoding of Goppa codes and their asymptotic behaviour.Algebraic geometry codes: algebraic curves and codes derived from them, Riemann-Roch theorem (statement only) and applications to algebraic geometry codes.
Learning Outcome	**Unit I:** The main outcome of this course is to develop the idea of Hamming codes, codes construction from hadamard matrices and plotkin bounds. **Unit II:** The main outcome of this unit to study the Reed-Muller codes of different orders and their encoding and decoding algorithm. **Unit III:** The main outcome of this unit is develop the idea of cyclic codes, Reed-Soloman codes, BCH Codes and their applications. **Unit IV:** The outcome of this unit is to develop the idea of construction of different kind of codes over Z4.
Text Books	1. J. H. van Lint, Introduction to Coding Theory, Springer, 1999. 2. W. C. Huffman and V. Pless, Fundamentals of Error Correcting Codes, Cambridge University Press, 2003.
Reference Books	1. J. MacWilliams and N. J. A. Sloane, The Theory of Error Correcting Codes, North Holland, 1977. 2. S. Ling and C. Xing, Coding Theory: A First Course, Cambridge University Press, 2004.

MCD569 | **Advance Optimization Techniques** | **L-T-P: 3-0-0**

Objective/Outcome: The course deals with the basic idea of Optimization techniques. We shall see how simple mathematics plays a significance role in the development of these ideas. Further, explore the different approaches to find the solution for the various Optimization Problems. The student will able to identify the appropriate methods to solve the different kinds of Optimization Problems.

Course Content	**Unit-I** **8 Lecturers** **Queuing Theory:** Structure of a Queuing System, Performance Measures of Queuing System, Probability Distributions in Queuing System, Single Server Queuing Models. **Unit-II** **8 Lecturers** **Inventory Control:** Deterministic Inventory problems with Shortages and without Shortages, problems of EOQ with price breaks, Systems of Inventory Control, One Period problem with Set-Up Cost and without Set-Up Cost. **Unit-III** **6 Lecturers** **Goal Programming:** Concept of Goal Programming, Model Formulation, Difference between LP and GP Approach, Graphical Solution Method for GP, Modified Simplex Method for GP. **Unit-IV** **7 Lecturers** **Simulation:** Types, Advantages and Disadvantages of Simulation, Monte Carlo Simulation, Simulation of Inventory and queuing Problems. **Markov Analysis:** Characteristics of a Markov Chain, State and Transition Probabilities, Multi-Period Transition Probabilities. **Unit-V** **10 Lecturers** **Classical Optimization Methods:** Unconstrained optimization problem, Optimizing multivariable functions, Constrained multivariable optimization with equality constraints: Direct substitution method, Lagrange multipliers method, Constrained multivariable optimization with inequality constraints: Kuhn-Tucker Necessary and Sufficient Conditions, Saddle-Point Criteria.
Learning Outcome	**Unit I:** Students will analyze the variety of performance measures of a queuing system. **Unit II:** Students will understand the meaning of inventory control as well as the use of various selective inventory control techniques to classify inventory items into broad categories. **Unit III:** This will help in distinguish between LP and GP methods for solving a business decision problem. **Unit IV:** To understand the basic concept of the simulation and apply Monte Carlo simulation technique for solving various types of problems. They will be able to construct a matrix of transition probabilities to compute long-term steady-state conditions. **Unit V:** Students will drive Kuhn-Tucker necessary conditions for an optimal solution for the constrained and unconstrained optimization problem.
Text Books	1. Johannes Jahn, Introduction to the Theory of Nonlinear Optimization, Third Edition, Springer, 2007. 2. J. Jahn, Vector Optimization - Theory, Applications, and Extensions, Springer, 2004.
Reference Books	1. H.A. Taha, Operationals Research: An Introduction, 1971. 2. F.S. Hillier and G.J. Libeberman, Introduction to Operationals Research, 1967.

MCD570 **Nonlinear Programming** **L-T-P: 3-0-0**

Objective/Outcome

The course deals with the basic idea of Optimization techniques. We shall see how simple mathematics plays a significance role in the development of these ideas. Further, explore the different approaches to find the solution for the various Optimization Problems. The student will able to identify the appropriate methods to solve the different kinds of Optimization Problems.

Course Content	**Unit I** **11 Lectures** **Convex Analysis:** Affine Sets, Convex Sets and Cones, Algebra of Convex Sets, Convex Functions and Its Properties, Differentiable and Subgradients of Convex Functions, Generalizations of Convex Functions. **Unit II** **8 Lectures** **Constraint Qualifications:** The Cone and Tangents, Linearly Constraint Qualification, Linear Independent Constraint Qualification, Mangasarian-Fromovitz Constraint Qualification, Slater's Constraint Qualification, Abadie's Constraint Qualification. **Unit III** **10 Lectures** **The Fritz-John and Karush-Kuhn-Tucker Optimality Conditions:** Unconstrained Problems, Problems with Equality and Inequality Constraints, Second-Order Necessary and Sufficient Optimality Conditions for Constrained Problems. **Unit IV** **10 Lectures** **Lagrangian Duality and Saddle Point Optimality Conditions:** The Lagrangian Dual Problem, Duality Theorems and Saddle Point Optimality Conditions, Properties of the Dual Function, Formulating and Solving the dual problem, Getting the Primal Solution, Linear and Quadratic Programs.
Learning Outcome	**Unit I:** This unit provides the basic idea of convexity and its generalizations. Also, build the basic concept related to the convex function. **Unit II:** This unit will help students to learn different types of constraints qualifications. **Unit III:** This will help to obtain the necessary optimality conditions for constrained and unconstrained optimization problem under suitable conditions. **Unit IV:** Students will be able to optimize the optimization problem with the help of Lagrangian duality and saddle-point criteria.
Text Books	1. M.S. Bazaraa, H.G. Sherali, C.M. Shetty, Nonlinear Programming Theory and Algorithms, John Wiley and Sons, 2013. 2. R.T. Rockafellar, Convex Analysis, Princeton University Press, 2015.
Reference Books	1. G. Giorgi, A. Guerraggio, J. Thierfelder, Mathematics of Optimization: Smooth and Nonsmooth Case, Elesvier, 2004. 2. A. Bagirob, N. Karmitsa, M.M. Mäkelä, Introduction to Nonsmooth Optimization: Theroy, Practice and Software, Springer, 2014.

MCD571 **Hydrodynamics & Application to Groundwater** **L-T-P: 3-0-0**

Objective: To make an exposure in the field of Groundwater Hydrology

Outcome: The student may be able to handle the problems of groundwater hydrology through various mathematical techniques.

Course Content	**Unit-I** **9 Lectures** Groundwater contamination: Occurrence of Groundwater, Sources of Groundwater Contamination and its types. Geological formations and its Types, Properties of Geological formations. **Unit-II** **10 Lectures** Solute Transport Mechanism, Advection, Diffusion, Dispersion, Ficks Law of Diffusion, Hydrodynamic Dispersion and its equation, Dispersion Theory. **Unit-III** **10 Lectures** Mathematical Approaches: Analytical, Semi-analytical and Numerical approaches, Transform Techniques, Homotopy Analysis Methods, Finite Difference Methods, Finite Element Methods. **Unit-IV** **10 Lectures** Hydrodynamics dispersion problems with concentration type, Flux type and Mixed type boundary conditions, Analytical, Semi-analytical and Numerical solutions. Error Analysis.
Learning Outcome	**Unit I:** Knowledge about groundwater sources of contamination and geological properties. **Unit II:** Knowledge about transport mechanism and associated laws govern to deal with advection-dispersion equation. **Unit III:** Knowledge about various mathematical approaches to deal with solute transport problems. **Unit IV:** Knowledge about transformation of the physical model into mathematical model and their solutions.
Text Books	1. Batu, V. (2006). Applied flow and solute transport modeling in aquifers: Fundamental principles and analytical and numerical methods, CRC, Boca Raton, FL.
Reference Books	1. Bear, J. (1972). Dynamics of fluids in porous media, American Elsevier, New York 2. Liao, S. (2003). “Beyond Perturbation: Introduction to the Homotopy Analysis Method.” Modern Mechanics and Mathematics Series, Chapman and Hall/CRC Press. 3. Todd, D. K. and Mays, L. W. (2005). Groundwater Hydrology. 3rd Edition, John Wiley & Sons.

MCD572 **Dynamical Systems: Theory and Applications** **L-T-P: 3-0-0**

Objective: To make an exposure in the field of Dynamical system theory, Nonlinear dynamics and Chaotic modeling.
Outcome: The students may be able to handle the problems related to dynamical systems, Mathematical and Chaotic modelling and related real world situations.

Course Content	**Unit I** **8 Lectures** Dynamical systems- attractors, Sensitive to Initial Condition (SIC) test, 1D map, Logistic map, Poincare' maps, generalized Baker's map, Circle map. **Unit II** **8 Lectures** Bifurcations - Saddle-node bifurcation, Transcritical bifurcation, Pitchfork bifurcation, Hopf bifurcation, Global bifurcations of cycles, Melnikov's method for homoclinic orbits. **Unit III** **8 Lectures** Strange attractors and fractals dimensions, Henon map and Rossler system, Box-counting, pointwise and correlation, Hausdorff dimensions, Lyapunov exponent, Horseshoe map and symbolic dynamics. **Unit IV** **10 Lectures** Central manifold theory and Normal form theory and its Applications to vector fields, maps and the models with parameters. **Unit V** **5 Lectures** Chaotic transitions, intermittency, crisis, quasiperiodicity, controlling and synchronization of chaos.
Learning Outcome	**Unit I:** Broad understand of the concepts of Dynamical System Theory and their real world applications **Unit II:** It provides idea of analyzing the bifurcation scenario of different continuous and discrete dynamical systems. How to handle the extreme situation when dynamics changes? **Unit III:** It helps students in understanding the concept of chaotic dynamics and its visualization. Also the concept of fractal dynamics in real life situations. **Unit IV:** It helps to understand the different types of extreme situation/dynamics including crisis, transient state, intermittency. Also idea about synchronization and control of chaos.
Text Books	1. R. K. Upadhyay, S. R. Iyengar, Introduction to mathematical modeling and chaotic dynamics. Chapman and Hall/CRC, 2013. 2. S. H. Strogatz, Nonlinear Dynamics and Chaos with Applications to Physics, Biology, Chemistry, and Engineering, 1994.
Reference Books	1. L. Perko, Differential equations and dynamical systems, Springer Science & Business Media, 1991. 2. S. Wiggins, Introduction to applied nonlinear dynamical systems and chaos (Vol. 2). Springer Science & Business Media, 2003.

MCD573 **Mathematical Biology** **L-T-P: 3-0-0**

Objective: To make an exposure in the field of Mathematical Biology, Epidemiology and disease dynamics in space and time.

Outcome: The student may be able to handle the problems of ecology, epidemiology and eco-epidemiology through various mathematical and numerical techniques.

Course Content	**Unit-I** **10 Lectures** Single species models, Exponential growth model, logistic growth model, Gompertz growth model, Allee Effect, Harvest model, Delay model and Discrete-time model, Routh Hurwitz criteria, Kolmogorov Analysis, Stability analysis. **Unit II** **10 Lectures** Lotka-Volterra model, Interacting population model, prey-predator model, competition model, mutualism models and chemostate model. **Unit III** **10 Lectures** Spatially structured models, Reaction-diffusion systems, Dynamics of exploited populations. **Unit IV** **9 Lectures** SI, SIS, SIR and SEIR models, spatial dynamics of disease spread, Introduction to Neural models, HH model, FHN model ML model HR models and its dynamics.
Learning Outcome	**Unit I:** It provides idea about how to model the real life situations for a single population. It gives broad Idea about continuous, discrete and delay situations. **Unit II:** It provides idea of formulating the model of two, three and many interacting populations. How to effectively analyze the evolutionary trend of such models and its stability behaviour. **Unit III:** It helps students in formulating the spatial and spatiotemporal dynamics. Also in understanding the dynamics of exploited populations. It helps to understand the modeling and dynamics of epidemiological systems. **Unit IV:** It helps to understand the modeling of Neural systems and the Brain dynamics.
Text Books	1. R. K. Upadhyay, S. R. Iyengar, Introduction to mathematical modeling and chaotic dynamics. Chapman and Hall/CRC, 2013. 2. M. Kot, Elements of Mathematical Ecology. Cambridge University Press, 2001.
Reference Books	1. J. D. Murray, Mathematical Biology I: An Introduction. Springer-Verlag, 1989. 2. A. Okubo, S. A. Levin, Diffusion and ecological problems: modern perspectives (Vol. 14). Springer Science & Business Media, 2013.

MCD574 **Statistical Reliability Theory** **L-T-P: 3-0-0**

Objective: The objective of this course is to impart knowledge about various concepts of reliability.

Outcome: Having perused this course, student will be able to conduct research on reliability both in Statistics and engineering sciences.

Course Content	**Unit I** **6 Lectures** Life distributions, Survival functions, Hazard rate, Residual life time, Mean residual life function, Common life distributions, Proportional Hazard models. **Unit II** **10 Lectures** Notions of ageing, IFR, DFR, IFRA, DFRA, NBU, NWU, NBUE, NWUE, DMLR, IMRL, DLR, ILR. **Unit III** **12 Lectures** System Reliability: components and systems, coherent systems; reliability coherent systems, cuts and paths, bounds and system reliability; closure under formation of coherent structures, Convolutions and mixture of these, structural and reliability importance components. **Unit IV** **11 Lectures** Univariate and bivariate shock models, Notions of bivariate and multivariate and dependence; Maintenance and replacement policies, Availability of repairable systems, Optimization of system reliability with redundancy
Learning Outcome	**Unit I:** This unit helps the student understand the basic measure of reliability. **Unit II:** This unit provides the knowledge of aging in reliability. **Unit III:** This unit provides the concept of system reliability. **Unit IV:** This unit helps the student understand different aspects of system reliability**.**
Reference Books	1. Barlow R.E. and Proschan, F. (1985). Statistical Theory of Reliability and Life Testing, Holt Rinehart and Winston, New York. 2. Bain L.J. (1991). Statistical Analysis of Reliability and Life Testing Models, Marcel Dekker, New York 3. Shaked M. and Shanthikumar J.G.(1994). Stochastic Orders and Their Applications, Academic Press.

MCO501 **Discrete Mathematics** **L-T-P: 3-0-0**

Objective(s): To learn about proof techniques, To learn about combinatorics and graph theory, To provide a background of mathematics that will be used in theoretical computer science.

Outcome: To be able to relate the computer science problems using discrete mathematical structures.

Course Content	**Unit I :** **12 Lectures** Propositional and predicate logic, well-formed formulas, tautologies, equivalences, normal forms, rules of inference, Proof Techniques, Boolean Algebra, Boolean Expressions, Optimization of Boolean Expressions, CNF, DNF, Karnaugh Map, Quine McKluskey Method. **Unit II** **5 Lectures** Sets and classes, Relations and functions, Recursive definitions, Posets, Lattices, Zorn's lemma, Cardinal and Ordinal numbers. **Unit III** **8 Lectures** Permutation and Combinations, Pigeonhole principle, Inclusion-Exclusion Principle, Recurrence relations, Methods for solving recurrence relations, Generating Functions., Master Theorem (without proof), Partitions (Stirling and Bell Numbers). **Unit IV** **7 Lectures** Modular Arithmetic, Euclid's Algorithm, primes, Chinese Remainder, Public Key Cryptography, RSA algorithm **Unit V** **7 Lectures** Graphs and Digraphs, Adjacency and Incidence matrices, Eulerian cycle and Hamiltonian cycle, Trees, Counting Spanning Trees.
Learning Outcome	**Unit I:** Students will learn predicate calculus which will help them in converting statements as mathematical statements. They will also learn several proof techniques. Students will learn the algebra behind the optimization of circuits. **Unit II:** Students will learn the concepts of set theory and their uses. **Unit III:** Students will learn combinatorics from this unit. **Unit IV:** This unit will help students in learning basic modular arithmetic which can be used in theoretical computer science. **Unit V:** Students will learn about graph structures and their uses in computer science.
Text Books	**1.** K. H. Rosen, Discrete Mathematics and its Applications, 6th Edition, Tata McGraw Hill, 2007 **2**. J. L. Hein, Discrete Structures, Logic, and Computability, 3rd Edition, Jones & Bartlett Learning, 2009.
Reference Books	**1.** R. P. Grimaldi, Discrete and Combinatorial Mathematics, 5th Edition, Pearson Education, 2002. **2**. J. P. Tremblay, R. Manohar, Discrete Mathematical Structures with Application to Computer Science, McGraw Hill, 1975.

MCO531 **Stochastic Processes** **L-T-P: 3-0-0**

Prerequisite:
Objective: The objective of the course will be to give idea to the students about various Stochastic Processes.
Outcome: This course will be useful for analysis of different financial market data, Business data.

Course Content	**Unit I** **9 Lectures** Definition and classification of general stochastic processes. Markov Chains: definition, transition probability matrices, classification of states, limiting properties. **Unit II** **11 Lectures** Chains with Discrete State Space: Poisson process, birth and death processes. Renewal Process: Renewal Process when Time is discrete, Renewal Process when Time is continues, Renewal Theory and Analysis. **Unit III** **9 Lectures** Markov Process with Continuous State Space: Introduction to Brownian motion, Wiener Process, Differential equation of Wiener Process, Kolmogorov Equations. **Unit IV** **6 Lectures** Markov Decision Process, Branching Process **Unit V** **4 Lectures** Congestion Process: Queuing Process, M/M/1 Queue
Learning Outcome	**Unit I:** This unit will help students to understand basics of Stochastics Processes and Markov Chain. **Unit II:** This unit will help students to understand different type of Point processes and their applications. **Unit III:** This unit will help students to get the concept different continuous State processes with application in finance. **Unit IV:** This unit will help students to get the concept of Markov decision process and its applications. **Unit V:** This unit will help students to get the concept of Queuing theory and its application.
Text Books	1. Stochastic Processes by J. Medhi, New Age International Publication.
Reference Books	1. Elements of Applied Stochastic Processes by U.N. Bhat, John Wiley and Sons. 2. Probability and Statistics with Reliability, Queuing, and Computer Science Applications by K.S. Trivedi, Prentice Hall of India.

MCO532 **Advanced Multivariate Analysis** **L-T-P: 3-0-0**

Prerequisite:
Objective: This course will demonstrate the properties of multivariate distributions and their applications.
Outcome: **S**tudents will learn about the application of Multivariate Analysis techniques in Data Analytics.

Course Content	**Unit I** **7 Lectures** Review of multivariate normal distribution and its properties, distributions of linear and quadratic forms, tests for partial and multiple correlation coefficients and regression coefficients and their associated confidence regions. Wishart distribution. **Unit II** **7 Lectures** Construction of tests, likelihood ratio principles, inference on mean vector, Hotelling's T^2. MANOVA. Inference on covariance matrices **Unit III** **12 Lectures** Discriminant analysis. Principal component analysis, factor analysis and clustering. Unified approach for constructions of probability distributions on $\boldsymbol{R^p}$ **Unit IV** **6 Lectures** Dimension reduction techniques: Principal component and generalized canonical variable analysis –constructions and related inference problems. **Unit V** **7 Lectures** Large *p*–small *n* problems in testing of multi parameter hypotheses: Tests for the mean vector in $\boldsymbol{N_p}(\mu,\Sigma)$, null and non-null asymptotic distributions of their test statistics.
Learning Outcome	**Unit I:** Demonstrate the properties of multivariate distributions such as multivariate normal, Wishart distribution etc. and their applications **Unit II:** Inference on parameters of the multivariate normal distributions and constructions of different tests, MANOVA etc. **Unit III:** Understanding discriminant analysis and principal component analysis for analyzing multivariate data. **Unit IV:** Use principal component analysis effectively for data exploration and data dimension reduction for high dimensional data **Unit V:** Students will learn the theory of statistical inference for high dimensional data analysis.
Text Books	1. T. W. Anderson (1984), An Introduction to Multivariate Statistical Analysis. 2nd Ed. John Wiley C. E. Leiserson, R. L. Rivest, C. Stein: Introduction to algorithms, PHI, 3rd Edition, 2010.
Reference Books	1. R. A. Johnson and D. W. Wichern (2013), Applied Multivariate Statistical Analysis. 6th Ed. Pearson 2. C. R. Rao (2002), Linear Statistical Inference and its Applications. 2nd Ed. Wiley 3. M. S. Srivastava and C. G. Khatri (1979), An Introduction to Multivariate Statistics, Elsevier North Holland, Inc., New York 4. R. J. Muirhead (2009). Aspects of Multivariate Statistical Theory. 2nd Ed. Wiley-Interscience.

MCO533 **Numerical Linear Algebra** **L-T-P: 3-0-0**

Prerequisite:
Objective: The objective of the course will be to give idea to the students about Numerical Linear Algebra.
Outcome: Students will get an exposure to Matrix Iterative Methods for Analysis Real Life System.

Course Content	**Unit I** **6 Lectures** LU factorization, Pivoting, Cholesky decomposition, Iterative refinement, QR factorization, Gram-Schmidt orthogonalization. **Unit II** **7 Lectures** Projections, Householder reflectors, Givens rotation, Singular Value Decomposition, Rank and matrix approximations, image compression using SVD, Least squares and least norm solution of linear systems **Unit III** **7 Lectures** Pseudoinverse, normal equations, Eigenvalue problems, Gershgorin theorem, Similarity transform, Eigenvalue & eigenvector computations and sensitivity, Power method, Schur decomposition, Jordan canonical form, QR iteration with & without shifts. **Unit IV** **7 Lectures** Hessenberg transformation, Rayleigh quotient, Symmetric eigenvalue problem, Jacobi method, Divide and Conquer, Computing the Singular Value Decomposition, Golub-Kahan-Reinsch algorithm, Chan SVD algorithm, Generalized SVD, Generalized and Quadratic eigenvalue problems. **Unit V** **12 Lectures** Generalized Schur decomposition (QZ decomposition), Iterative methods for large linear systems: Jacobi, Gauss-Seidel and SOR, convergence of iterative algorithms. Krylov subspace methods: Lanczos, Arnoldi, MINRES, GMRES, Conjugate Gradient and QMR, Pre-conditioners, Approximating eigenvalues and eigenvectors.
Learning Outcome	**Unit I:** Understanding the concept of factorization of matrix into two product of two matrices. **Unit II:** Student will able to understand the SVD and its application in real life problem. **Unit III:** Solving eigenvalue and eigenvector problem using numerical linear algebraic technique. **Unit IV:** Student will learn algorithm for the computation of singular value computation. **Unit V:** Students will able to solve the large linear system of equations using Krylov subspace methods.
Text Books	1. B.N. Dutta, Numerical Linear Algebra and Applications, SIAM, 2010.
Reference Books	1. R. Bellman, Introduction to Matrix Analysis, SIAM, 1997 2. R.S. Varga, Matrix Iterative Analysis, Springer, 2000.