# Institute of Infrastructure, Technology, Research And Management

## Syllabus for Written Test

## PhD Admission Autumn Semester (2022-23)

### Part-I

### Research Methodology -Common for all Engineering disciplines (e.g.: Civil, Electrical, Computer Science, Mechanical and Aero Space)

**Introduction to engineering research**: Definition, characteristics and types, basic research terminology, qualities of a researcher, research methods vs methodology, overview of engineering research methods, role of Information and Communication Technology (ICT) in research, research ethics, intellectual property rights and scholarly publishing.

**Research formulation:** Defining and formulating the research problem, selecting the problem, necessity of defining the problem, literature survey significance in defining a problem, various sources, critical review, identifying gap areas from literature review and research databases, development of working hypothesis.

**Research design and data analysis:** Research design basic principles, need of research design, features of good design, important concepts relating to research design, observation and facts, laws and theories, method validation, observation and collection of data, methods of data collection, sampling methods, data processing and analysis, hypothesis testing, generalization and interpretation.

**Technical writing:** Types (thesis, report, journal papers etc.), qualities, structure and components of good technical document, use of software tools (Word processing, latex, etc.), illustrations and tables, bibliography, referencing and footnotes. Oral presentation planning, software tools, creating and making effective presentation, use of visual aids, importance of effective communication.

## Part-II
## Department of Civil Engineering

**Candidate shall attempt any ONE SECTION of choice.**

### Section A

**1. Structural Engineering**

Fundamentals of Engineering mechanics, solid mechanics, structural analysis, design of RCC structures, design of steel structures, structural dynamics, construction materials and management, Earthquake Engineering.

### Section B

**2. Water Resources Engineering**

Fluid Mechanics, Hydrology: Precipitation, Stream flow measurements, Hydrographs, Flood and Flood Routing, Open Channel Hydraulics: Introduction, Uniform Flow, Energy-Depth Relationships, Gradually Varied Flow-Theory & Computations, Rapidly Varied Flow-Hydraulic Jump, Unsteady Flows.

### Section C

**3. Geotechnical Engineering**

Index and engineering properties of soils, slope stability, subsurface exploration, shallow foundations, deep foundations, earth retaining structures, ground improvement techniques.

### Section D

**4. Transportation Engineering**

- Traffic Engineering – Fundamental parameters of Traffic Flow : Macroscopic and Microscopic Time space diagram : one vehicle & multiple vehicle Fundamental flow diagram : Speed Vs density; flow Vs density; speed Vs flow, Flow Models
- Highway Geometric Design – Horizontal and Vertical Alignment, Sight Distance, etc.
- Pavement Engineering – Pavement design, Pavement materials, Pavement maintenance.

### Section E

**5. Environmental Engineering**

- Water treatment: Sources of water, Quality and quantity of water, Drinking water standards, water requirements, water chemistry, basic unit operations and processes for water treatment.
- Wastewater treatment: Primary, secondary and tertiary treatment of wastewater, sludge disposal, effluent discharge standards.
- Air Pollution: Types of pollutants, their sources and impacts, Air quality standards, air pollution meteorology.

## Part-II
## Department of Electrical and Computer Science Engineering

(The Part II have two option A or B, candidate may choose any one depending upon specialization)

**Electrical Engineering (A):**

**Engineering Mathematics:** Linear Algebra: Matrix Algebra, Systems of linear equations, Eigenvalues, Eigenvectors Calculus: Mean value theorems, Theorems of integral calculus, Evaluation of definite and improper integrals, Partial Derivatives, Maxima and minima, Multiple integrals, Fourier series, Vector identities, Directional derivatives, Line integral, Surface integral, Volume integral, Stokes's theorem, Gauss's theorem, Divergence theorem, Green's theorem. Differential equations: First order equations (linear and nonlinear), Higher order linear differential equations with constant coefficients, Method of variation of parameters, Cauchy's equation, Euler's equation, Initial and boundary value problems, Partial Differential Equations, Method of separation of variables. Complex variables: Analytic functions, Cauchy's integral theorem, Cauchy's integral formula, Taylor series, Laurent series, Residue theorem, Solution integrals. Probability and Statistics: Sampling theorems, Conditional probability, Mean, Median, Mode, Standard Deviation, Random variables, Discrete and Continuous distributions, Poisson distribution, Normal distribution, Binomial distribution, Correlation analysis, Regression analysis.

**Electric circuits:** Network elements, Ideal voltage and current sources, dependent sources, R, L, C, M elements; Network solution methods: KCL, KVL, Node and Mesh analysis; Network Theorems: Thevenin's, Norton's, Superposition and Maximum Power Transfer theorem; Transient response of dc and ac networks, sinusoidal steady-state analysis, resonance, two port networks, balanced three phase circuits, star-delta transformation, complex power and power factor in ac circuits.

**Electromagnetic Fields**: Coulomb's Law, Electric Field Intensity, Electric Flux Density, Gauss's Law, Divergence, Electric field and potential due to point, line, plane and spherical charge distributions, Effect of dielectric medium, Capacitance of simple configurations, Biot-Savart's law, Ampere's law, Curl, Faraday's law, Lorentz force, Inductance, Magnetomotive force, Reluctance, Magnetic circuits, Self and Mutual inductance of simple configurations.

**Signals and Systems:** Representation of continuous and discrete time signals, shifting and scaling properties, linear time invariant and causal systems, Fourier series representation of continuous and discrete time periodic signals, sampling theorem, Applications of Fourier Transform for continuous and discrete time signals, Laplace Transform and Z transform. R.M.S. value, average value calculation for any general periodic waveform

**Electrical Machines:** Single phase transformer, equivalent circuit, phasor diagram, open circuit and short circuit tests, regulation and efficiency; Three-phase

transformers: connections, vector groups, parallel operation; Auto-transformer, Electromechanical energy conversion principles; DC machines: separately excited, series and shunt, motoring and generating mode of operation and their characteristics, speed control of DC motors; Three-phase induction machines: principle of operation, types, performance, torque- speed characteristics, no-load and blocked-rotor tests, equivalent circuit, starting and speed control; Operating principle of single-phase induction motors; Synchronous machines: cylindrical and salient pole machines, performance and characteristics, regulation and parallel operation of generators, starting of synchronous motors; Types of losses and efficiency calculations of electric machines.

**Power Systems:** Basic concepts of electrical power generation, ac and dc transmission concepts, Models and performance of transmission lines and cables, Economic Load Dispatch (with and without considering transmission losses), Series and shunt compensation, Electric field distribution and insulators, Distribution systems, Per-unit quantities, Bus admittance matrix, Gauss- Seidel and Newton-Raphson load flow methods, Voltage and Frequency control, Power factor correction, Symmetrical components, Symmetrical and unsymmetrical fault analysis, Principles of over-current, differential, directional and distance protection; Circuit breakers, System stability concepts, Equal area criterion.

**Control Systems:** Mathematical modeling and representation of systems, Feedback principle, transfer function, Block diagrams and Signal flow graphs, Transient and Steady-state analysis of linear time invariant systems, Stability analysis using Routh-Hurwitz and Nyquist criteria, Bode plots, Root loci, Lag, Lead and Lead Lag compensators; P, PI and PID controllers; State space model, Solution of state equations of LTI systems.

**Electrical and Electronic Measurements:** Bridges and Potentiometers, Measurement of voltage, current, power, energy and power factor; Instrument transformers, Digital voltmeters and multimeters, Phase, Time and Frequency measurement; Oscilloscopes, Error analysis.

**Analog and Digital Electronics:** Simple diode circuits: clipping, clamping, rectifiers; Amplifiers: biasing, equivalent circuit and frequency response; oscillators and feedback amplifiers; operational amplifiers: characteristics and applications; single stage active filters, Sallen Key, Butterworth, VCOs and timers, combinatorial and sequential logic circuits, multiplexers, demultiplexers, Schmitt triggers, sample and hold circuits, A/D and D/A converters.

**Power Electronics:** Static V-I characteristics and firing/gating circuits for Thyristor, MOSFET, IGBT; DC to DC conversion: Buck, Boost and Buck-Boost Converters; Single and three-phase configuration of uncontrolled rectifiers; Voltage and Current commutated Thyristor based converters; Bidirectional ac to dc voltage source converters; Magnitude and Phase of line current harmonics for uncontrolled and thyristor based converters; Power factor and Distortion Factor of ac to dc converters; Single-phase and three phase voltage and current source inverters, sinusoidal pulse width modulation.

**Part 2: Electronics Engineering (B)**

**Engineering Mathematics: Linear Algebra**: Vector space, basis, linear dependence and independence, matrix algebra, eigenvalues and eigenvectors, rank, solution of linear equations- existence and uniqueness.
**Calculus:** Mean value theorems, theorems of integral calculus, evaluation of definite and improper integrals, partial derivatives, maxima and minima, multiple integrals, line, surface and volume integrals, Taylor series.

**Differential Equations**: First order equations (linear and nonlinear), higher order linear differential equations, Cauchy's and Euler's equations, methods of solution using variation of parameters, complementary function and particular integral, partial differential equations, variable separable method, initial and boundary value problems.

**Vector Analysis**: Vectors in plane and space, vector operations, gradient, divergence and curl, Gauss's, Green's and Stokes' theorems.

**Complex Analysis**: Analytic functions, Cauchy's integral theorem, Cauchy's integral formula, sequences, series, convergence tests, Taylor and Laurent series, residue theorem.

**Probability and Statistics**: Mean, median, mode, standard deviation, combinatorial probability, probability distributions, binomial distribution, Poisson distribution, exponential distribution, normal distribution, joint and conditional probability

**Networks, Signals and Systems: Circuit analysis**: Node and mesh analysis, superposition, Thevenin's theorem, Norton's theorem, reciprocity. Sinusoidal steady state analysis: phasors, complex power, maximum power transfer. Time and frequency domain analysis of linear circuits: RL, RC and RLC circuits, solution of network equations using Laplace transform, Linear 2-port network parameters, wye-delta transformation. **Continuous-time signals**: Fourier series and Fourier transform, sampling theorem and applications, **Discrete-time signals**: DTFT, DFT, z-transform, discrete-time processing of continuous-time signals. LTI systems: definition and properties, causality, stability, impulse response, convolution, poles and zeroes, frequency response, group delay, phase delay

**Electronic Devices:** Energy bands in intrinsic and extrinsic semiconductors, equilibrium carrier concentration, direct and indirect band-gap semiconductors, **Carrier transport**: diffusion current, drift current, mobility and resistivity, generation and recombination of carriers, Poisson and continuity equations, P-N junction, Zener diode, BJT, MOS capacitor, MOSFET, LED, photo diode and solar cell

**Analog Circuits: Diode circuits**: clipping, clamping and rectifiers, **BJT and MOSFET amplifiers**: biasing, ac coupling, small signal analysis, frequency response. Current mirrors and differential amplifiers,

**Op-amp circuits**: Amplifiers, summers, differentiators, integrators, active filters, Schmitt triggers and oscillators

**Digital Circuits: Number representations**: binary, integer and floating-point-numbers. Combinatorial circuits: Boolean algebra, minimization of functions using Boolean identities and Karnaugh map, logic gates and their static CMOS implementations, arithmetic circuits, code converters, multiplexers, decoders.

**Sequential circuits**: latches and flip-flops, counters, shift-registers, finite state machines, propagation delay, setup and hold time, critical path delay, **Data converters**: sample and hold circuits, ADCs and DACs.

**Semiconductor memories**: ROM, SRAM, DRAM, **Computer organization**: Machine instructions and addressing modes, ALU, data-path and control unit, instruction pipelining

**Control Systems:** Basic control system components; Feedback principle; Transfer function; Block diagram representation; Signal flow graph; Transient and steady-state analysis of LTI systems; Frequency response; Routh-Hurwitz and Nyquist stability criteria; Bode and root-locus plots; Lag, lead and lag lead compensation; State variable model and solution of state equation of LTI systems.

**Communications: Random processes**: autocorrelation and power spectral density, properties of white noise, filtering of random signals through LTI systems, **Analog communications**: amplitude modulation and demodulation, angle modulation and demodulation, spectra of AM and FM, super heterodyne receivers, **Information theory**: entropy, mutual information and channel capacity theorem, **Digital communications**: PCM, DPCM, digital modulation schemes (ASK, PSK, FSK, QAM), bandwidth, inter-symbol interference, MAP, ML detection, matched filter receiver, SNR and BER. Fundamentals of error correction, Hamming codes, CRC.

**Electromagnetics: Maxwell's equations**: differential and integral forms and their interpretation, boundary conditions, wave equation, Poynting vector, **Plane waves and properties**: reflection and refraction, polarization, phase and group velocity, propagation through various media, skin depth, **Transmission lines**: equations, characteristic impedance, impedance matching, impedance transformation, S-parameters, Smith chart, Rectangular and circular waveguides, light propagation in optical fibers, dipole and monopole antennas, linear antenna arrays.

## Part-II
## Department of Electrical and Computer Science Engineering
## (The syllabus for candidates applying for Computer Science is below:)

**Computer Science:**

**Basic Mathematics**: linear algebra: vector and matrix properties and operations, solving systems of linear equations; probability and statistics, random variables, random processes

**Basic Programming Concepts**: Iterative programming (for and while loop constructs), conditional executions, functions, pointers, recursions, fIle handling, procedural and object oriented programming concepts

**Data Structures**: Linear data structures: arrays, stack, queue, linked lists; non-linear data structures: binary search tree, balanced binary search tree, heap tree, graphs; representation of data structures in computer memory; applications and complexity of operations on / using data structures

**Design and Analysis of Algorithms:** Asymptotic notations, sorting and search-insertion sort, selection sort, merge sort, quicksort, binary search, design techniques: divide and conquer, greedy, dynamic programming, data structures: heaps, union of disjoint sets, search trees, algorithms on graphs: exploration, connectivity, shortest paths, directed acyclic graphs, spanning trees, Intractability: NP completeness, reductions

**Computer networks:** TCP/IP protocol stack and design of Internet, application layer: HTTP, FTP, DNS, P2P file sharing, transport layer: Issues related to process-to process communication and reliable data transfer, TCP and UDP operations; network layer: routing, addressing, QoS issues, IPv4 and IPv6 protocols; data link layer: wired and wireless local area networks and protocols

**Digital Logic Design:** Boolean algebra, logic gates, design of combinational logic circuits - adder, subtractor, multiplier, comparator; sequential logic circuits - flip-flops, registers, counters

**Computer Organization:** Machine instructions and addressing modes. ALU, data-path and control unit. Instruction pipelining, pipeline hazards. Memory hierarchy: cache, main memory and secondary storage; I/O interface (interrupt and DMA mode)

**Theory of Computation:** Regular expressions and finite automata. Context-free grammars and push-down automata. Regular and contex-free languages, pumping lemma. Turing machines and undecidability

**Compiler Design:** Lexical analysis, parsing, syntax-directed translation. Runtime environments. Intermediate code generation. Local optimisation, Data flow analyses: constant propagation, liveness analysis, common subexpression elimination

**Databases:** ER-model. Relational model: relational algebra, tuple calculus, SQL. Integrity constraints, normal forms. File organization, indexing (e.g., B and B+ trees). Transactions and concurrency control

**Operating Systems:** Interprocess communication, deadlock, memory management, file system design, device/IO management

## Part-II
## Department of Mechanical and Aero-Space Engineering

**Classification of Metal Removal Processes and Machine tools:** Introduction to Manufacturing and Machining, Basic working principle, configuration, specification and classification of machine tools. Turning, milling, drilling, boring, abrasive processes, super-finishing processes etc.

**Mechanics of Machining (Metal Cutting) and Machinability:** Geometry of single point cutting tools, Conversion of tool angles from one system to another, Mechanism of chip formation, Orthogonal and oblique cutting, Use of chip breaker in machining, Machining forces and Merchant's Circle Diagram (MCD), Analytical and Experimental determination of cutting forces, Dynamometers for measuring cutting forces, Cutting temperature – causes, effects, assessment and control, Control of cutting temperature and cutting fluid application, Concept of Machinability and its Improvement, Failure of cutting tools and tool life, Cutting Tool Materials of common use Advanced Cutting Tool Materials.

**Casting:** Introduction, Solidification- Solidification of pure metals and alloys; nucleation and growth in alloys; solidification of actual castings; progressive and directional solidification; centerline feeding resistance; rate of solidification; Chvorinov's Rule, Risering- Riser design, Gating- Gating systems and their characteristics; the effects of gates on aspiration; turbulence and dross trap, Patterns, Inspection and Quality Control.

**Metal Forming and Sheet Metal Working:** Elastic and plastic deformation. Concept of strain hardening. Hot and cold working processes -rolling, forging, extrusion, swaging, wire and tube drawing. Machines and equipment for the processes. Analysis of stress and strains, Yield criteria, Parameters and force calculations. Test methods for formability. Specific roll pressure, Rolling load, Rolling torque, Blanking, Punching, piercing, bending, drawing etc. Analysis of drawing of circular wires, Forces in blanking, Stresses and strains in bending.

**Welding:** Introduction: Principle of welding, general applications such as construction of bridges, towers, automobiles & electronic circuits, etc. Classification of welding processes, Soldering and brazing**.** Welded Joints: Introduction to AWS standards. Manual metal arc (MMA) or shielded metal arc (SMA) welding, Submerged arc welding (SAW). Gas metal arc welding (GMAW) or MIG/MAG welding, TIG welding, Resistance welding. Current–voltage characteristic of arc, Effects of change in arc current for change in arc length, Heat flow characteristics.

**Introduction to Plastics & their Processing:** Introduction to plastics, Injection moulding, Extrusion, Blow moulding, calendaring, etc.

**Jigs and Fixtures:** Purposes of jigs and fixtures and their Design principles, Design and Application of typical jigs and fixtures.

**Introduction to Materials science and characterization**

Importance, properties and classification of materials, structure of materials, equilibrium diagrams, strengthening mechanisms teat treatments of steels, powder metallurgy.

**Stresses and Strains**

Stresses, Strains, Modulus of elasticity (E), Modulus of rigidity (G), Bulk Modulus (K), Yield Stresses, Ultimate Stress, Factor of safety, shear stress, Poisson's ratio. Relationship between E, G and K, bars of varying sections, deformation due to self-weight, composite sections, temperature stress.

General equation for transformation of stress, principal planes and principal stresses, maximum shear stress, stress determination using Mohr's circle, Principal stresses in shafts subjected to combined torsion, bending & axial thrust, and concept of equivalent torsional and bending moment.

**Shear Force and Bending Moment in Beams**

Axial force, shear force and bending moment diagrams for statically determinate beams including beams with internal hinges for different types of loading. Relationship between rate of loading, shear force and bending moment.

**Theory of Simple Bending and Shear stresses**

Flexure formula for straight beam, moment of inertia, transfer theorem, polar moment of inertia, simple problems involving application of flexure formula, section modulus, moment of resistance, flitched beams.

Beam Deflection – Assumptions and Derivations, Double Integration and Macaulay's method Moment Area Method and Conjugate Beam Method, Energy methods for deflection

Distribution of shear stress across plane sections commonly used for structural purposes, shear connectors.

**Theory of Simple Torsion**

Torsion in circular shafts-solid & hallow, stresses in shaft when transmitting power, closed coil helical spring under axial load

**Columns and Walls**

Struts subjected to axial loading, concept of buckling, Euler's formula for struts with different support conditions, limitation, Euler's and Rankine's design formulae. Application to member's subjected to eccentric loads, core of section, problems on chimneys, retaining walls etc. involving lateral loads.

**Thin Cylindrical and Spherical Shells**

Derivation for circumferential and longitudinal stresses for cylindrical and spherical shells under internal pressure and examples

Thermodynamic equilibrium and quasi-static processes, Measurement of temperature and calibration of thermometers, the ideal gas temperature scale, Measurement of pressure, Bourdon pressure gage and manometers, gage and absolute pressure.

**Energy Transfer:** Work Transfer (definition and calculation), Different modes of work, Displacement Work for various process, Heat Transfer; Modes of heat transfer, Basic laws in conduction, convection and radiation, combined modes of heat transfer

**Review of First law:** First law applied to a system undergoing a cyclic process and a change of state, concept of energy. Application of First Law to control volumes; Nozzle, Diffuser, Compressor, Turbine, Throttling device, Heat Exchanger (only steady flow need be considered).

General Thermodynamic property relations: The Maxwell relations, The TdS relations, Difference in heat capacities; Ratio of heat capacities, The Joule-Thomson coefficient

**Review of Second law:** Ideal processes, Carnot Cycle, Corollaries of second law, Carnot's theorem, Absolute thermodynamic temperature scale, Clausius inequality; Entropy: Definition, Principles of increase of entropy, calculation entropy for various processes; Available Energy and Availability: Helmholtz and Gibbs functions, Availability in steady flow, Entropy equation for flow processes, irreversibility.

**Air Standard Cycles:** Carnot, Stirling, Ericsson, Otto, Diesel, and Dual cycles. Brayton cycle: intercooling, reheating and regeneration.

**Vapour Cycles:** Carnot cycle; Simple Rankine cycle, Techniques for efficiency improvement, Reheat and Regenerative cycles with open & closed feed water heater.

**Vapour Power and Steam Turbines:** *Steam Generator:* Mounting and Accessories, Circulation, fuels and combustions. Steam Nozzles: Types of nozzles, critical pressure ratio and condition for maximum discharge, nozzle efficiency. *Steam Turbine:* Principle and types of steam turbines, compounding of steam turbines, velocity diagram and analysis of steam turbine, condition for maximum efficiency, degree of reaction, reheat factor, governing of steam turbine – throttle, nozzle and bypass governing, Losses in steam turbine, cogeneration. Back pressure, pass out and mixed pressure turbine.

**Internal Combustion Engine and Gas Turbines:** Fuels, Fuel air cycle, actual cycle, SI and CI engines, Combustion in SI and CI engines, Carburetors, Fuel injection, MPFI, performance analysis of the IC engine, Lubrication and cooling system, Hybrid engine

**Gas Turbine:** Principle and Classification, optimum pressure ratio for maximum thermal efficiency, work ratio, air rate, effect of operating variables on the thermal efficiency and work ratio, and air rate, analysis of gas turbine.

**Gas Compressors**

Compressor: Classification; single and multistage; effect of intercooling in reciprocating compressors; volumetric efficiency and power requirement. Centrifugal compressor: classification, energy transfer equations, elementary theory, vector diagram efficiencies; elementary analysis of axial compressors. Roots blower, performance analysis.

**Properties of Fluids:**

Introduction, Fluid properties and classification; concept of viscosity, compressibility and Elasticity, Surface tension and capillarity. Newton's law of viscosity, dynamic viscosity, classification of fluids, kinematic viscosity, variation of viscosity with temperature, Surface tension and capillarity.

**Fluid Statics:**

Pascal law, Hydrostatic law, Relative equilibrium, Pressure measurements-atmospheric pressure, Absolute pressure, Gauge pressure, and Vacuum pressure, Piezometer, Mano-Meters, Forces on immersed bodies: Drag and Lift.

**Fluid Kinematics:**

Fluid flow methods of analysis of fluid motion, Streamlines, Path lines, Streak lines and Stream tubes. Types of fluid flow-Steady and unsteady flow, Uniform and non-uniform flow, Laminar and turbulent flow, Reynolds number, Reynolds experiment, Rotational and Irrotational flow, Subcritical, critical and Supercritical flow, Compressible and Incompressible flow, One, Two and three dimensional flow, Circulation and vorticity, Stream function and Flownet.

**Fluid Dynamics:**

Equation of Motion: Euler's equation, Bernoulli's equation, Energy correction factor, Coefficients of contraction, velocity and discharge, Differential head meters, Free vortex motion, Analysis of free liquid Jet, Cavitation. Linear momentum equation, Force on pipe junctions and bends, Forces on moving plates and vanes due to fluid flow, Angular momentum, Forced vortex.

**Flow Measuring Devices:**

Measurement of discharge-Venturimeter, Orifice meter, mouth pieces, Nozzle meter, Rotometer, Weirs, Flow under sluice gates. Time of empting tanks with or without inflow. Measurement of velocity-Pitot tube.

**Hydraulic Machines:** Turbines: classification of tribunes, Impulse and Reaction turbines, characteristic curves, draft tubes, Pumps: classification of pumps, centrifugal pump, efficiency and power, Output of centrifugal pumps, characteristics curves.

**Pipe Hydraulics:**

Review of the basic equations: continuity, momentum, and energy. Flow through closed conduits: Laminar flow, Turbulent flow.

Pipe Flow Problems: Losses in pipe flow, pipes in series, pipes in parallel, branching pipes, siphons, multi-reservoir problems, pipe networks, unsteady flow in pipes, water hammer analysis.

**Introduction to linear programming:** Different types of models, formulation of linear programming problems (LPPs), product-mix problems, deterministic models, graphical solution

**Linear Programming (Simplex Method):** Various steps in solving or problems using simplex method. (a) Maximization problems, (b) Minimization problems , minimisation problems (all constraints of the type >), BIG 'M' method. Minimising case – constraints of mixed types (< and >), Maximisation case-constraints of mixed type.

**Duality and Sensitivity:** Duality and its concept, dual linear programming, application of elementary sensitivity analysis.

**Transportation problem:** Balanced Transportation Problem, Unbalanced Transportation Problem, Method of Solution, Degeneracy and the Transportation Problem, Testing the Solution for Optimality, Solution of Unbalanced Transportation Problem, Maximization and the Transportation Techniques.

**Assignment Model:** Assignment Table, Method of Solving Assignment Problems.

**Network optimization:** Network Optimization Models,Example, The Terminology of Networks, The Shortest-Path Problem, The Minimum Spanning Tree Problem , The Maximum Flow Problem.

**PERT/CPM:** Using a Network to Visually Display a Project, Scheduling a Project with PERT/CPM, Dealing with Uncertain Activity Durations, An Evaluation of PERT/CPM.

**Queuing Theory :** Queuing systems and concepts, classification of queuing situations; Kendall's notation, solution of queuing problems, single channel, single stage, finite and infinite queues with Poisson arrival and exponential service time, applications to industrial problems.

**Forecasting:** Judgmental Forecasting, Time Series, Forecasting Errors

**Inventory Model:** Components, Deterministic, Continuous-Review, Models, Deterministic, Periodic-Review Model