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DEPARTMENT OF OPERATIONAL RESEARCH

Semester-III

DISCIPLINE SPECIFIC CORE COURSE – 7: CONVEX AND DISCRETE OPTIMIZATION

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Convex and Discrete Optimization (DSC-7)	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To impart knowledge of central concepts and methods of nonlinear convex optimization problems.
- To impart knowledge of central concepts and methods of discrete optimization problems.
- Formulations of various real-world problems arising in science, engineering, and management.

Learning outcomes

Students completing this course will be able to:

- Understand the concepts of convex functions and their properties and describe the convex Optimization problem.
- Analyse the difference between local and global optimal solutions and define the optimality conditions for unconstrained and constrained optimization problems.
- Apply their learning by formulating real-world problems under various categories such as assignment, matching, knapsack, capital budgeting, set covering and partitioning, routing, and scheduling as linear integer programming problems.
- Describe the theoretical workings of the solution methods for linear integer programming problems and demonstrate their working by hand and solver
- Describe the theoretical workings of the solution methods for quadratic programming problems and demonstrate their working by hand and solver

SYLLABUS OF DSC-7

Unit I **(9 Hours)**

Unconstrained Optimization: Unconstrained optimization problems, Types of extrema and their necessary and sufficient conditions, Line search methods, Gradient ascent/descent method, Steepest ascent/descent method

Unit II **(12 Hours)**
Convex Optimization: Convex functions and properties, Operations preserving convexity, Fritz-John and Karush-Kuhn-Tucker optimality conditions for constrained optimization problems, Lagrange dual function, and dual problem

Unit III **(9 Hours)**
Quadratic Optimization: Quadratic programming, Wolfe's and Beale's method, Duality, Applications

Unit IV **(15 Hours)**
Discrete Optimization: Introduction to linear integer programming problem, Real-world applications of linear integer programming problem, Branch and bound method, Gomory's cutting plane method for pure and mixed linear integer programming problem, 0-1 programming problem, E-Bala's algorithm for 0-1 programming problem

Practical component (if any) – (30 Hours)
Practical/Lab to be performed on a computer using OR/Statistical packages

1. Solution of linear integer programming problem using Branch and bound method.
2. Solution of Fixed charge problem.
3. Solution of linear integer programming problem using Gomory's cutting plane method.
4. Solution of Capital budgeting problem.
5. Solution of Knapsack problem.
6. Solution of Set covering problem.
7. Determine local/relative optima of a given unconstrained problem.
8. Test whether the given function is concave/convex.
9. Test whether the given matrix is positive definite/negative definite/semi-positive definite/semi-negative definite.
10. Solution of convex optimization problems using Karush-Kuhn-Tucker conditions.
11. Solution of Quadratic programming problems by Wolfe's method.
12. Solution of Quadratic programming problem by Beal's method.

Essential Readings:

- Bazaraa, M. S., Sherali, H. D., & Shetty, C. M. (2006). *Nonlinear programming-Theory and algorithms (3rd ed.).* New Delhi: John Wiley & Sons (Indian print).
- Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical optimization with applications*. New Delhi: Narosa Publishing House.

Suggested Readings:

- Antoniou, A., & Lu, Wu-Sheng (2007). *Practical optimization- Algorithms and engineering applications*. New York: Springer.

- Hillier, F. S., & Lieberman, G. J. (2010). *Introduction to operations research- Concepts and cases (9th ed.).* New Delhi: Tata McGraw Hill (Indian print).

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 8: ADVANCED CALCULUS

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Advanced Calculus (DSC-8)	4	3	1	0	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint the students with the advanced concepts in Calculus
- To make the students learn effective methods of calculus
- To make the student understand the quantitative change in the behaviour of the variables and apply them on the problems related to problems under Operational Research domain

Learning Outcomes

Students completing this course will be able to:

- Understand the concepts of function of one variable to functions of two or more variables.
- Evaluate double and triple integral based problems
- Analyse integration based problems in real life cases.
- Understand Calculus and derivatives of vectors.
- Derive and apply Gauss Divergence Theorem, Green's Theorem, Stroke's Theorem

SYLLABUS OF DSC-8

Unit I **(12 Hours)**

Function of Two Variables, Limits and continuity, Partial differentiation, Total differential, Approximation, Higher order partial derivative, Homogeneous Function, Taylor's Theorem for two variables, Maxima and Minima functions of Two Variables, Lagrange Multiplier and Constrained optimization.

Unit II **(12 Hours)**
Multiple Integral: Double Integral, Double Integration over rectangular and nonrectangular regions, Triple Integral, Triple integral over a parallelopiped and solid regions, Volume by triple integrals, Change of variables in integrals.

Unit III **(12 Hours)**
Vector Calculus, Laws of Vector Algebra, Dot Product, Cross Product, Vector and Scalar Fields, Ordinary Derivative of Vectors, Space Curves, Partial Derivatives, Del Operator, Gradient of a Scalar Field, Directional Derivative, Gradient of Matrices, Divergence of a Vector Field, Curl of a Vector Field.

Unit IV **(9 Hours)**
Gauss Divergence Theorem, Green's Theorem, Stroke's Theorem.

Practical component (if any) – Nil , Tutorial: 15 Hours

Essential/recommended readings

- Prasad, Gorakh (2016). *Differential Calculus (19th ed.)*. Pothishala Pvt. Ltd. Allahabad.
- Jain, R. K., & Iyengar, S. R. (2007). *Advanced engineering mathematics*. Alpha Science Int'l Ltd..
- Kreyszig, E. (2007). *Advanced Engineering Mathematics 9th Edition* with Wiley Plus Set (p. 334). John Wiley & Sons.
- Strang, G. (1991). *Calculus (Vol. 1).* SIAM.
- Marsden, J., & Weinstein, A. (1985). *Calculus I*. Springer Science & Business Media.

Suggestive readings

- Shanti Narayan and P K Mittal (2018). *Differential Calculus. 15th Ed (Revised).*, S Chand Publication, New Delhi
- Shanti Narayan and P K Mittal (2016). *Integral Calculus. 11th Ed (Revised*), S Chand Publication, New Delhi.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 9: QUEUING THEORY

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Queuing Theory (DSC-9)	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To introduce queuing (waiting lines) models and their applications in real-life situations.
- To provide necessary mathematical support and confidence to the students to tackle real life problems.
- To make students learn both theory and applications of fundamental and advanced models in this field.

Learning outcomes

Students completing this course will be able to:

- Understand the concepts of stochastic processes, Markov processes, Markov chains and apply these in analysing queuing systems.
- Understand the concepts and analyse the mathematical theory related to queuing systems.
- Analyse and compute quantitative measures of performance for queuing systems.
- Apply and extend queuing models to analyse real world systems.

SYLLABUS OF DSC-9

Unit I **(12 Hours)**
Stochastic processes: definition and classification on the basis of state and parameter space. Markov chain: definition, transition probability matrix (TPM), classification of states. Continuous-time Markov chains: Poisson process (definition and its relationship with exponential distribution), pure birth process and pure death process.

Unit II **(6 Hours)**
Queueing systems: basic characteristics, measures of performance and Kendall's notation. Little's formula, traffic intensity and some general results for G/G/1 and G/G/c queues.

Unit III **(12 Hours)**
General birth-death processes. Simple Markovian queueing models: single-server queue (M/M/1), multi-server queue (M/M/c), queue with finite capacity (M/M/c/K), Erlang's loss formula (M/M/c/c), queues with unlimited service (M/M/∞), finite-source queues, queues with impatience (M/M/1 with balking and M/M/1 with reneging).

Unit IV **(9 Hours)**
Advanced queueing models: general queueing model (M/G/1 queue), Pollaczek–Khinchine formula for M/G/1 queue, deterministic queueing model (M/D/1 queue), and Erlangian queueing model ($M/E_k/1$ queue).

Unit V **(6 Hours)**
Design and control of queueing models. Queueing simulation.

Practical component (if any) – (30 Hours)

1. Finding measures of performance for deterministic queuing system.
2. Finding measures of performance for M/M/1 queuing system with infinite capacity.
3. Finding measures of performance for M/M/1 queuing system with finite capacity.
4. Finding measures of performance for M/M/c queuing system with infinite capacity.
5. Finding measures of performance for M/M/c queuing system with finite capacity.
6. Finding measures of performance for any Markovian queuing system with multiple servers and with finite/infinite capacity.

Essential/recommended readings

- Cooper, R. B. (1981). *Introduction to Queueing Theory* (2nd Edition). North Holland.
- Kleinrock L. (1975). *Queueing Systems*, Volume 1: Theory, John Wiley.
- Gross, Donald, Shortle , John F., Thompson, James M., and Harris, Carl M. (2008). *Fundamentals of Queueing Theory* (5th Edition), John Wiley and Sons Inc. Pte. Ltd.
- Bhat, U. N. (2008). *An introduction to Queueing Theory: Modelling and Analysis in Applications (Statistics for Industry and Technology)*. Birkhauser Boston.
- Cox, D. R. and Smith ,W. L. (1991). *Queues*. Chapman and Hall/CRC.
- Medhi, J. (2002). *Stochastic Models in Queueing Theory* (2nd Edition), Academic Press.
- Satty, T. L. (1983). *Elements of Queueing Theory with Applications*, Dover Publications, NY.
- Prabhu, N. U. (2012). *Foundations of Queueing Theory (International Series in Operations Research & Management Science)*, Springer.

Suggestive readings-Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category II

B.A. Programme with Operational Research as Major discipline

DISCIPLINE SPECIFIC CORE COURSE – 5: CONVEX AND DISCRETE OPTIMIZATION

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Convex and Discrete Optimization (DSC-5)	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To impart knowledge of central concepts and methods of nonlinear convex optimization problems.
- To impart knowledge of central concepts and methods of discrete optimization problems.
- Formulations of various real-world problems arising in science, engineering, and management.

Learning outcomes

Students completing this course will be able to:

- Understand the concepts of convex functions and their properties and describe the convex Optimization problem.
- Analyse the difference between local and global optimal solutions and define the optimality conditions for unconstrained and constrained optimization problems.
- Apply their learning by formulating real-world problems under various categories such as assignment, matching, knapsack, capital budgeting, set covering and partitioning, routing, and scheduling as linear integer programming problems.
- Describe the theoretical workings of the solution methods for linear integer programming problems and demonstrate their working by hand and solver
- Describe the theoretical workings of the solution methods for quadratic programming problems and demonstrate their working by hand and solver

SYLLABUS OF DSC-5

Unit I **(9 Hours)**

Unconstrained Optimization: Unconstrained optimization problems, Types of extrema and their necessary and sufficient conditions, Line search methods, Gradient ascent/descent method, Steepest ascent/descent method

Unit II **(12 Hours)**
Convex Optimization: Convex functions and properties, Operations preserving convexity, Fritz-John and Karush-Kuhn-Tucker optimality conditions for constrained optimization problems, Lagrange dual function, and dual problem

Unit III **(9 Hours)**
Quadratic Optimization: Quadratic programming, Wolfe's and Beale's method, Duality, Applications

Unit IV **(15 Hours)**
Discrete Optimization: Introduction to linear integer programming problem, Real-world applications of linear integer programming problem, Branch and bound method, Gomory's cutting plane method for pure and mixed linear integer programming problem, 0-1 programming problem, E-Bala's algorithm for 0-1 programming problem

Practical component (if any) – **(30 Hours)**
Practical/Lab to be performed on a computer using OR/Statistical packages

1. Solution of linear integer programming problem using Branch and bound method.
2. Solution of Fixed charge problem.
3. Solution of linear integer programming problem using Gomory's cutting plane method.
4. Solution of Capital budgeting problem.
5. Solution of Knapsack problem.
6. Solution of Set covering problem.
7. Determine local/relative optima of a given unconstrained problem.
8. Test whether the given function is concave/convex.
9. Test whether the given matrix is positive definite/negative definite/semi-positive definite/semi-negative definite.
10. Solution of convex optimization problems using Karush-Kuhn-Tucker conditions.
11. Solution of Quadratic programming problems by Wolfe's method.
12. Solution of Quadratic programming problem by Beal's method.

Essential Readings:

- Bazaraa, M. S., Sherali, H. D., & Shetty, C. M. (2006). *Nonlinear programming-Theory and algorithms (3rd ed.)*. New Delhi: John Wiley & Sons (Indian print).
- Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical optimization with applications.* New Delhi: Narosa Publishing House.

Suggested Readings:

- Antoniou, A., & Lu, Wu-Sheng (2007). *Practical optimization- Algorithms and engineering applications.* New York: Springer.

- Hillier, F. S., & Lieberman, G. J. (2010). *Introduction to operations research- Concepts and cases (9th ed.).* New Delhi: Tata McGraw Hill (Indian print).

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 6: QUEUING THEORY

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Queuing Theory (DSC-6)	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To introduce queueing (waiting lines) models and their applications in real-life situations.
- To provide necessary mathematical support and confidence to the students to tackle real life problems.
- To make students learn both theory and applications of fundamental and advanced models in this field.

Learning outcomes

Students completing this course will be able to:

- Understand the concepts of stochastic processes, Markov processes, Markov chains and apply these in analysing queuing systems.
- Understand the concepts and analyse the mathematical theory related to queuing systems.
- Analyse and compute quantitative measures of performance for queuing systems.
- Apply and extend queuing models to analyse real world systems.

SYLLABUS OF DSC-6

Unit I **(12 Hours)**

Stochastic processes: definition and classification on the basis of state and parameter space. Markov chain: definition, transition probability matrix (TPM), classification of states. Continuous-time Markov chains: Poisson process (definition and its relationship with exponential distribution), pure birth process and pure death process.

Unit II **(6 Hours)**

Queueing systems: basic characteristics, measures of performance and Kendall's notation. Little's formula, traffic intensity and some general results for G/G/1 and G/G/c queues.

Unit III **(12 Hours)**

General birth-death processes. Simple Markovian queueing models: single-server queue (M/M/1), multi-server queue (M/M/c), queue with finite capacity (M/M/c/K), Erlang's loss formula (M/M/c/c), queues with unlimited service (M/M/∞), finite-source queues, queues with impatience (M/M/1 with balking and M/M/1 with reneging).

Unit IV **(9 Hours)**

Advanced queueing models: general queueing model (M/G/1 queue), Pollaczek–Khinchine formula for M/G/1 queue, deterministic queueing model (M/D/1 queue), and Erlangian queueing model ($M/E_k/1$ queue).

Unit V **(6 Hours)**

Design and control of queueing models. Queueing simulation.

Practical component (if any) – **(30 Hours)**

1. Finding measures of performance for deterministic queuing system.
2. Finding measures of performance for M/M/1 queuing system with infinite capacity.
3. Finding measures of performance for M/M/1 queuing system with finite capacity.
4. Finding measures of performance for M/M/c queuing system with infinite capacity.
5. Finding measures of performance for M/M/c queuing system with finite capacity.
6. Finding measures of performance for any Markovian queuing system with multiple servers and with finite/infinite capacity.

Essential/recommended readings

- Cooper, R. B. (1981). *Introduction to Queueing Theory* (2nd Edition). North Holland.
- Kleinrock L. (1975). *Queueing Systems*, Volume 1: Theory, John Wiley.
- Gross, Donald, Shortle , John F., Thompson, James M., and Harris, Carl M. (2008). *Fundamentals of Queueing Theory* (5th Edition), John Wiley and Sons Inc. Pte. Ltd.
- Bhat, U. N. (2008). *An introduction to Queueing Theory: Modelling and Analysis in Applications (Statistics for Industry and Technology)*. Birkhauser Boston.
- Cox, D. R. and Smith ,W. L. (1991). *Queues*. Chapman and Hall/CRC.
- Medhi, J. (2002). *Stochastic Models in Queueing Theory* (2nd Edition), Academic Press.
- Satty, T. L. (1983). *Elements of Queueing Theory with Applications*, Dover Publications, NY.
- Prabhu, N. U. (2012). *Foundations of Queueing Theory (International Series in Operations Research & Management Science)*, Springer.

Suggestive readings-Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category III

(B.A Programme with Operational Research as non-Major or Minor discipline)

DISCIPLINE SPECIFIC CORE COURSE – 3: MATHEMATICAL MODELLING FOR BUSINESS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Modelling for Business (DSC-3)	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To introduce fundamental issues in production and inventory planning
- Develop the students' modelling and analytical skills
- Introduce the basic concepts in Marketing and its important role in Business.

Learning outcomes

Students completing this course will be able to:

- Create understanding towards explaining the meaning of Inventory control, various forms and functional role of Inventory
- Evaluate the Economic Order Quantity (EOQ) for various deterministic inventory models.
- Understand quantity discount models in inventory management.
- Analyse and demonstrate solution methods for production scheduling problems
- Understand the role of marketing in an organization, different marketing decisions and scientific marketing analysis
- Derive joint optimization models of price, quality and promotional efforts
- Perform Brand switching analysis to find the equilibrium market share
- Create and Analyse media allocation problem for advertisement
- Apply the knowledge of various pricing strategies to grab maximum market share

SYLLABUS OF DSC-3

Unit I **(6 Hours)**

Inventory Management: Concepts and problems in inventory systems, Selective inventory classification and its use in controlling inventory, Different types of costs in inventory systems and method of their estimation.

Unit II **(18 Hours)**

Deterministic Inventory models with and without lead time, and with and without shortages. Determination of reorder level (ROL), Quantity discount models, Production scheduling problems.

Unit III **(9 Hours)**

Concept of marketing and its role in an organization. Marketing decisions, scientific marketing analysis. Uses and limitations of mathematical models in marketing, Classification of market structure in competitive conditions.

Unit IV **(12 Hours)**

Demand elasticity, Joint optimization of price, quality and promotional efforts. Pricing decisions, Media allocation for advertisement, Brand switching analysis.

Practical component (if any) – (30 Hours)

1. Problems based on selective inventory classification (ABC and FNS analysis).
2. To find optimal inventory policy for deterministic inventory models.
3. To solve all units quantity discount model.
4. To solve Incremental quantity discount model.
5. Solution of procurement/production scheduling model.
6. Problems based on joint optimization of price, quality and promotional efforts.
7. Problems based on media allocation for advertisement.
8. Problems based on Brand switching analysis.

Essential/recommended readings

- Axsäter, S. (2015). *Inventory control* (3rd ed.). New York: Springer.
- Hillier, F.S., Lieberman, G. J., Nag, B., & Basu, P. (2017). *Introduction to operations research- concepts and cases* (10th ed.). New Delhi: Tata McGraw Hill (Indian print).
- Hooley, G. J., & Hussey, M. K. (1999). *Quantitative methods in marketing* (2nd ed.). London: International Thomson Business Press.
- Kotler P., & Keller, K. L. (2008), *Marketing management* (13th ed.). New Delhi: Pearson Education, Ltd.
- Naddor, E. (1966). *Inventory systems*. New York: Wiley.
- Waters, D. (2003). *Inventory control and management (2nd ed.).* West Sussex: John Wiley & Sons Ltd.

Suggestive readings:

- Silver, E. A., Pyke, D. F., & Peterson, R. (1998). *Inventory management and production planning and scheduling* (3rd ed). New Jersey: John Wiley & Sons, Inc.
- Taha, H. A. (2017). *Operations research-an introduction* (10th ed.). New Delhi: Pearson Prentice Hall (Indian print).

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category IV

BSc. Physical Sciences/ Mathematical Sciences with Operational Research as one of the three Core Disciplines

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

DISCIPLINE SPECIFIC CORE COURSE – 3: MATHEMATICAL MODELLING FOR BUSINESS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Modelling for Business (DSC-3)	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To introduce fundamental issues in production and inventory planning
- Develop the students' modelling and analytical skills
- Introduce the basic concepts in Marketing and its important role in Business.

Learning outcomes

Students completing this course will be able to:

- Create understanding towards explaining the meaning of Inventory control, various forms and functional role of Inventory
- Evaluate the Economic Order Quantity (EOQ) for various deterministic inventory models.
- Understand quantity discount models in inventory management.
- Analyse and demonstrate solution methods for production scheduling problems
- Understand the role of marketing in an organization, different marketing decisions and scientific marketing analysis
- Derive joint optimization models of price, quality and promotional efforts
- Perform Brand switching analysis to find the equilibrium market share
- Create and Analyse media allocation problem for advertisement
- Apply the knowledge of various pricing strategies to grab maximum market share

SYLLABUS OF DSC-3

Unit I **(6 Hours)**

Inventory Management: Concepts and problems in inventory systems, Selective inventory classification and its use in controlling inventory, Different types of costs in inventory systems and method of their estimation.

Unit II **(18 Hours)**

Deterministic Inventory models with and without lead time, and with and without shortages. Determination of reorder level (ROL), Quantity discount models, Production scheduling problems.

Unit III **(9 Hours)**

Concept of marketing and its role in an organization. Marketing decisions, scientific marketing analysis. Uses and limitations of mathematical models in marketing, Classification of market structure in competitive conditions.

Unit IV **(12 Hours)**

Demand elasticity, Joint optimization of price, quality and promotional efforts. Pricing decisions, Media allocation for advertisement, Brand switching analysis.

Practical component (if any) – **(30 Hours)**

1. Problems based on selective inventory classification (ABC and FNS analysis).
2. To find optimal inventory policy for deterministic inventory models.
3. To solve all units quantity discount model.
4. To solve Incremental quantity discount model.
5. Solution of procurement/production scheduling model.
6. Problems based on joint optimization of price, quality and promotional efforts.
7. Problems based on media allocation for advertisement.
8. Problems based on Brand switching analysis.

Essential/recommended readings

- Axsäter, S. (2015). *Inventory control* (3rd ed.). New York: Springer.
- Hillier, F.S., Lieberman, G. J., Nag, B., & Basu, P. (2017). *Introduction to operations research- concepts and cases* (10th ed.). New Delhi: Tata McGraw Hill (Indian print).
- Hooley, G. J., & Hussey, M. K. (1999). *Quantitative methods in marketing* (2nd ed.). London: International Thomson Business Press.
- Kotler P., & Keller, K. L. (2008), *Marketing management* (13th ed.). New Delhi: Pearson Education, Ltd.
- Naddor, E. (1966). *Inventory systems*. New York: Wiley.
- Waters, D. (2003). *Inventory control and management (2nd ed.).* West Sussex: John Wiley & Sons Ltd.

Suggestive readings:

- Silver, E. A., Pyke, D. F., & Peterson, R. (1998). *Inventory management and production planning and scheduling* (3rd ed). New Jersey: John Wiley & Sons, Inc.
- Taha, H. A. (2017). *Operations research-an introduction* (10th ed.). New Delhi: Pearson Prentice Hall (Indian print).

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

CATEGORY-V

COMMON POOL OF DISCIPLINE SPECIFIC ELECTIVES (DSE) COURSES OFFERED BY THE DEPARTMENT

DISCIPLINE SPECIFIC ELECTIVE (DSE-1 (a)): SIMULATION MODELLING & APPLICATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Simulation Modelling and Applications (DSE-1(a))	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint students with the fundamentals of Simulation modelling
- Develop the students' analytical skills
- Introduce simulation techniques applicable in different situations

Learning outcomes

Students after completing this course will be able to:

- Know the basics of simulation modelling and its scope.
- Gain knowledge of Event Type Simulation and its applications in real life.
- Understand the various methods of random number generation.
- Understand and use Monte Carlo Simulation.
- Apply Simulation Technique in Inventory Control, Queuing Systems.
- Use Simulation in Finance and Investment, Maintenance Problems and Networks.

SYLLABUS OF DSE-1(a)

Unit I **(15 Hours)**
Introduction to Simulation: What is Simulation, Process of Simulation, Advantages and Limitations of Simulation, Classification of Simulation Models, Continuous Event Type Simulation, Discrete Event Simulation: Components and Organization, Application of discrete event simulation in single server queueing system, inventory model and insurance risk model.

Unit II **(12 Hours)**
Random Number Generation: Pseudo Random Number Generators – Mixed Congruence Method, Multiplicative Congruential Method, Additive Congruential Method, the inverse transform method, Discrete and Continuous Distributions, Box Muller Method.

Unit III **(9 Hours)**
Monte Carlo Simulation, Application of Simulation in Inventory Control, Simulation of Queueing Systems.

Unit IV **(9 Hours)**
Simulation of Maintenance Problems, Applications of Simulation in Finance and Investment, Simulation of Job Sequencing, Simulation of Networks.

Practical component (if any) – (30 Hours)

Practical/Lab to be performed on a computer using OR/Statistical packages

1. Modelling randomness in Excel: Pseudo Random Number generators
2. Generation of U (0,1)
3. Simulating M/M/1 Queues
4. Monte Carlo Simulation
5. Simulation in Inventory Control
6. Forecasting using Simulation
7. Simulation in Queueing System using Monte Carlo Simulation
8. Simulation in Finance and Investment

Essential/recommended readings

- Fishman, G.S. (1996). *Monte Carlo-Concepts, Algorithms and Applications*, Springer
- Taha, H.A. (2018), *Operations Research, An Introduction, 10h Edition*, Pearson.
- Sheldon M. Ross (2008), *Simulation, 4thEd*, Elsevier.
- Averill M. Law and W. David Kelton (2003), *Simulation Modeling and Analysis*, 3rd Ed., Tata McGraw-Hill.

Suggestive readings:

Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE-1 (b)): NUMERICAL ANALYSIS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Numerical Analysis (DSE-1(b))	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint students with the techniques that uses algorithms for approximation problems.
- Develop the students' ability to use various numerical method techniques
- To make the students formulate and apply appropriate strategy to solve real world problems.

Learning outcomes

Students after completing this course will be able to:

- Know the basic elements of numerical methods and error analysis
- Learn Iterative methods for finding the roots of the algebraic and transcendental equations
- Apply the numerical methods to solve system of linear equations and understand the methods convergence analysis.
- Understand the concepts of finite differences, derive the interpolation formulae and understand its applications.

SYLLABUS OF DSE-1(b)

Unit I **(12 Hours)**

Errors: Relative Error, Absolute Error, Round off Error, Truncation Error. Transcendental and Polynomial equations: Bisection method, Newton-Raphson method, Secant method. Method of False Position, Fixed point iterative method, Order and rate of convergence of these methods.

Unit II **(9 Hours)**

System of linear equations: Gauss Elimination and Gauss Jordan methods. Gauss Jacobi method, Gauss Seidel method and their convergence analysis.

Unit III **(9 Hours)**

Interpolation: Lagrange Interpolating Polynomial, Newton's Gregory forward and backward difference interpolating polynomial, Newton's Divided Difference Interpolating Polynomial, Error analysis in each method.

Unit IV **(15 Hours)**

Numerical Integration: Trapezoidal rule, Composite Trapezoidal rule, Simpson's rule, Composite Simpson's rule, Simpsons 3/8th rule. Ordinary Differential Equations: Euler's method, Modified Euler's method, Runge-Kutta method

Practical component (if any) – **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages for developing the following numerical programs:

1. Bisection method
2. Newton Raphson method
3. Secant method
4. Regula Falsi method
5. LU decomposition method
6. Gauss-Jacobi method
7. Gauss-Seidel method
8. Lagrange interpolation
9. Newton interpolation
10. Trapezoidal rule
11. Simpson's rule
12. Euler's method

Essential/recommended readings

- Sastry, S. S. (2012). *Introductory methods of numerical analysis*. PHI Learning Pvt. Ltd..
- Gerald, C. F., & Wheatley, P. O. (2008). *Applied Numerical Analysis (7th ed.)*. Pearson Education. India.
- Bradie, Brian. (2006). *A Friendly Introduction to Numerical Analysis*. Pearson Education, India. Dorling Kindersley (India) Pvt. Ltd. Third impression 2011.
- Mudge, M. R. (2003). *An introduction to numerical methods and analysis*,(Wiley).

Suggestive readings:

- Jain, M. K., Iyengar, S. R. K., & Jain, R. K. (2012). *Numerical Methods for Scientific and Engineering Computation. (6th ed.).* New Age International Publisher, India, 2016.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE-1 (c)): PRODUCTION AND OPERATIONS MANAGEMENT

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Production and Operations Management (DSE-1(c))	4	3	1	0	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To make students understand the strategic significance of Production and Operations Management in service and manufacturing organizations.
- To acquaint them with fundamental concepts, functions and applications of discipline, so as to deal with different types of problems faced by operations managers, and common decision-making approaches.

Learning Outcomes

Students completing this course will be able to:

- Gain an understanding of basic concepts of Production and Operations management and differentiate between them.
- Analyse the factors affecting Facility Capacity, Location, and Layout.
- Understand the Production planning and Material Requirement Planning techniques.
- Comprehend basic concepts in Just in time (JIT) Manufacturing System, Operations scheduling and Quality management.

SYLLABUS OF DSE-1(c)

Unit I **(9 Hours)**

Introduction to Production and Operations Management (POM): Overview of Production System, Objectives of Operations Management, Scope of Operations Management, Types of Production Systems, Production Design Process and Process choices. Framework for Managing Operations; Strategic Operations Management.

Unit II **(12 Hours)**

Facility Location, Layout and Capacity: Factors Influencing Plant Location, Single Facility Location Problem, Multi Facility Location Problem, Models for Facility Location Problem. Facility Layout decision- importance and benefits of layout planning, different types of layouts. Capacity Planning – Measures of capacity, factors affecting demand forecasting and capacity planning, short and long-term capacity planning.

Unit III **(12 Hours)**
Production Planning: Aggregate planning, Master Production Schedule. Introduction to MRP and MRP II. Lot sizing in MRP systems – Lot for lot method, economic quantity method, periodic order quantity method, part period balancing, Wagner – Whitin approach. Introduction to modern productivity techniques – Just in Time (JIT), Kanban system. Inventory Control – basic concepts, Classification of Inventory System, EOQ Model.

Unit IV **(12 Hours)**
Operations Scheduling and Quality Management: Flow Shop Scheduling- Introduction, Single Machine Scheduling, n jobs m machines, Johnsons' rule. Quality Management: Introduction, Statistical process control, control charts, Total Quality Management (TQM), Six sigma, ISO 9000 and other ISO series.

Practical component (if any) –Nil, Tutorial: 15 hrs.

Essential/recommended readings

- Bedi, K. (2013). *Production & Operations Management.* 3rd edition. Oxford University Press.
- Everett E. Adam, Ronald J Ebert (1995). *Production and Operations Management: Concepts, Models, and Behavior*. Fifth edition. PHI Learning Pvt. Ltd
- Gaither, N., & Frazier, G. (2002). *Operations management*. South-Western/Thomson Learning.
- Heizer,J., Render, B., Munson, C., & Sachan, A. (2017). *Operations Management*. Twelfth edition. Pearson Education.

Suggestive readings:

Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE-1 (d)): BUSINESS FORECASTING

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Business Forecasting (DSE-1(d))	**4**	**3**	**0**	**1**	**12th class with Mathematics**	**Nil**

Learning Objectives

The objective of this course is to introduce both managerial and technical aspects of business forecasting to students and expose them to its practical applications.
The Learning Objectives of this course are as follows:

- To introduce both managerial aspect of business forecasting
- Develop the students' ability to understand the technical aspect for business forecasting and its applications
- Introduce various forecasting techniques helpful for better decision making

Learning outcomes

Students completing this course will be able to:

- Gain an understanding of key concepts of Business Forecasting and its applications.
- Develop analytical methodologies that make prediction of future events of interest to business and industry.
- Make well-informed decisions that require forecasting of relevant variables.
- Identify relevant information to support model selection in scenarios where issues of time series analysis are involved.
- Predict relationships among business and economic variables for supporting short-term and long-term planning.

SYLLABUS OF DSE-1(d)

Unit I **(12 Hours)**

Introduction to Business Forecasting, Importance of forecasting, Different types of forecasting methods, Identification of appropriate technique for forecasting, Applications of forecasting methods in industry, Practical issues in forecasting.

Unit II **(15 Hours)**

Time series and its components, modelling and forecasting trend, modelling and forecasting seasonality, characterising cycles in times series, forecasting cycles, Forecasting models with trend seasonality and cycle.

Unit III **(9 Hours)**
Simple linear regression and multiple linear regression models and their applications in business.

Unit IV **(9 Hours)**
Stationary and non-stationary time series, Autoregressive (AR) Forecasting model, Moving average (MA) model, Autoregressive moving average model (ARMA), Autoregressive integrated moving average (ARIMA) model, Random walk model. Applications of these models in business.

Practical component (if any) – **(30 Hours)**
Practical/Lab to be performed on a computer using OR/Statistical packages

1. Plot and visualize time series data.
2. Fitting of trend by using Method of semi averages.
3. Fitting of trend by Moving Average Method.
4. Measurement of Seasonal indices using method of simple average.
5. Measurement of Seasonal indices using Ratio-to-Trend method.
6. Measurement of Seasonal indices using Ratio-to-Moving Average method.
7. Measurement of seasonal indices using Link Relative method.
8. To find cyclical variations using percentage of trend method and relative cyclical residual method.
9. Fitting a simple linear regression model for forecasting.
10. Fitting a multiple linear regression model for forecasting.

Essential/recommended readings

- Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (2008). *Forecasting methods and applications*. John wiley & sons.
- Pindyck, R. S., & Rubinfeld, D. L. (1976). *Econometric models and economic forecasts*. McGraw-Hill.
- Butler, W. F., Kavesh, R. A., & Platt, R. B. (Eds.). (1974). *Methods and techniques of business forecasting*. Prentice Hall.
- Diebold, F. X. (2004). *Elements of Forecasting*. Thompson: South Western. Ohio, USA.

Suggestive readings

- Hanke, J. E., & Wichern, D.W. (2014). *Business Forecasting.* Pearson.
- Gujarati, D. N. (2004). *Basic econometrics. (4th ed.),* McGraw-Hill.

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CATEGORY-VI

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES OFFERED BY THE DEPARTMENT

GENERIC ELECTIVES (GE-3): QUEUING AND RELIABILITY THEORY

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course
		Lecture	Tutorial	Practical/ Practice		
Queuing and Reliability Theory (GE-3)	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To make students understand the basic idea of random variables and their associated probability distributions as it is a prerequisite.
- To enrich students with the concept of stochastic processes and its applications in the field of queuing theory.
- To make students learn the mathematical theory of queuing systems.
- To introduce students with the concept of system reliability and make them learn to evaluate reliability of various system configurations.
- To provide students hands-on experience of the queuing and reliability models through practical sessions using certain software.

Learning outcomes

Students completing this course will be able to:

- Understand the concepts and mathematical theory related to queuing systems & system reliability required to understand, analyse and solve any real-world problem.
- Learn the concepts of stochastic processes, Markov processes, Markov chains and apply these mathematical models in real-life problems.
- Evaluate the performance metrics of any queuing system.
- Compute the system reliability of any type of system-configuration.
- Make use of software for problem analysis.

SYLLABUS OF GE-3

Unit I **(12 Hours)**

Basic characteristics of a queueing system, Kendall's notation, performance measures of a queueing system, Little's formula, Traffic intensity, Some general results for G/G/1 and G/G/c queueing models, Introduction to stochastic processes, Markov chain and Markov process, pure-birth process, pure-death process, birth-death process.

Unit II **(15 Hours)**

Markovian queuing models with single & multiple servers, finite & infinite system capacity, and finite & infinite population size, Cost analysis, Applications of queuing theory.

Unit III **(9 Hours)**

Introduction to reliability, reliability function, and related concepts like hazard rate, mean time to failure (MTTF), and mean time before failure (MTBF); classes of lifetime distributions, and hazard rate of Exponential and Weibull distributions.

Unit IV **(9 Hours)**

Reliability, hazard rate, MTSF of various system configurations- series, parallel, mixed configuration, k out of n system and stand-by system.

Practical component (if any) – **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages

1. Finding measures of performance for deterministic queuing system.
2. Finding measures of performance for M/M/1 queuing system with infinite capacity.
3. Finding measures of performance for M/M/1 queuing system with finite capacity.
4. Finding measures of performance for M/M/c queuing system with infinite capacity.
5. Finding measures of performance for M/M/c queuing system with finite capacity.
6. Finding measures of performance for any Markovian queuing system with multiple servers and with finite/infinite capacity.
7. Measuring reliability of different types of system configuration.
8. Measuring reliability, hazard rate and MTSF of different types of system configuration.

Essential/recommended readings

- Medhi J. (2009), *Stochastic Processes* (3rd Edition), New Delhi: New age science Ltd.
- Gross D., Shortle J. F, Thompson J. M., & Harris C. M. (2008), *Fundamentals of Queuing Theory* (4th edition), New Jersey: John Wiley & Sons, inc.
- Trivedi K. S. (2016), *Probability & Statistics with Reliability, Queuing & Computer Science applications*, New Jersey: John Wiley & Sons, Inc
- Srinath L. S., (2005), *Reliability Engineering*, New Delhi, East West Press.
- Rausand M. & Hoyland A. (2003), *System Reliability Theory: Models, Statistical Methods & Applications* (2nd ed.), New Jersey, John Wiley & Sons, Inc.
- Hiller F. S., Lieberman G. J., Nag B., Basu P. (2017). *Introduction to Operations Research- Concepts & Cases* (10th edition), New Delhi, Tata McGraw-Hill (Indian Print).
- Taha, H. A. (2019). *Operations Research-An Introduction* (10th ed.). New Delhi: Pearson Prentice Hall (Indian print).

Suggestive readings-Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.