Appendix-6
Resolution No. 57-1-2

Master of Operational Research

Two Year Programme

Structure I and II
(Semester III and IV)

(PG Curriculum Framework 2024 based on NEP 2020)

Academic Session 2025-26

Department of Operational Research
Faculty of Mathematical Sciences
University of Delhi
Delhi – 110007

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Master of Operational Research (MOR)

Programme Objectives:

- The Master of Operational Research (MOR) programme is a two-year postgraduate degree structured across four semesters in accordance with the PG Curriculum Framework 2024 based on NEP 2020. The programme integrates **Discipline-Specific Core (DSC)** courses, **Discipline-Specific Electives (DSE)**, **Generic Electives (GE)**, **Skill-Based Courses**, and an **Industrial Project/Dissertation** in the research-oriented structure.

- Semesters I and II emphasize the development of a strong theoretical and methodological foundation in Operational Research through core courses in optimization, queueing theory, statistics, programming, and data-driven modelling concepts that prepare students to work with real-world datasets and computational tools. Semesters III and IV provide opportunities for specialization through advanced electives and focus on applied learning, culminating in an Industrial Project that exposes students to practical problem-solving in industry, government, or non-government organizations.

- The overarching objective of the programme is to develop competent analysts and decision-support professionals equipped with rigorous quantitative skills, data-driven modelling capabilities, and research aptitude suitable for careers in business enterprises, consulting organizations, public-sector institutions, research establishments, and policy agencies.

Programme Specific Outcomes:

Upon successful completion of the programme, students will be able to:

- Apply analytical, mathematical, computational, and data-driven modelling skills acquired during coursework to formulate, analyse, and solve a wide range of operational and managerial problems.

- Demonstrate logical reasoning, quantitative aptitude, and structured problem-solving abilities necessary for addressing complex decision-making situations across business, public-sector, and social domains.

- Acquire comprehensive and in-depth knowledge of advanced theoretical principles, data analytics methodologies, and Operational Research tools, including optimization, stochastic modelling, simulation, forecasting, machine learning fundamentals, and decision sciences.

- Engage with current and emerging research trends by understanding state-of-the-art developments, contemporary data-driven techniques, and innovations in Operational Research and allied fields.

- Integrate theory with practice through an Industrial Project, enabling students to apply OR models, analytics techniques, and data-driven approaches to address significant operational, analytical, or policy-oriented challenges faced by industry, government, or non-government organizations, and to develop implementable solutions informed by real-world data and constraints.

PG Curriculum Framework 2024 based on NEP 2020

Course Structure:

Sem-I to Sem-IV, Structure-I of Two-Year PG Program in Operational Research, PGCF

1st year of PG curriculum structure for 2-year PG Program (Structure I and II)

Semester	DSC (12 Credits)	DSE 1, DSE 2 (8 Credits) OR DSE 1 & GE 1 (8 Credits)	Skill-based course/ workshop/Specialized Laboratory/Internship/ Apprenticeship/Hands-on Learning (2 Credits)	Dissertation/ Academic Project/ Entrepreneurship	Total Credits	Pool of GE to be offered for the students of other departments
	Credit Distribution: (4 * 3) = 12	**Credit Distribution: (4 * 2) = 8**	**Credit Distribution: (2*1) = 2**		**(12+8+2) = 22**	
Semester I	DSC-1: Inventory Management DSC-2: Linear Programming & Extensions DSC-3: Statistics	**Pool of DSE:** DSE-1(a): Mathematics for OR DSE-1(b): Decision Theory DSE-1(c): Design Thinking and Innovation DSE-1(d): Game Theory with Behavioral Aspects DSE-1(e): Simulation Modeling DSE-1(f): Software Engineering	SBC-1: Database Management System	NIL		GE-1(a): Inventory Management GE-1(b): Linear Programming & Extensions GE-1(c): Game Theory with Behavioral Aspects GE-1(d): Simulation Modeling

1st year of PG curriculum structure for 2-year PG Program (Structure I and II)

Semester	DSC (12 credits)	DSE-3 and DSE-4 (8 credits) OR DSE-2 and GE-2 (8 credits)	Skill-based course/ workshop/ Specialized Laboratory/Internship/ Apprenticeship/Hands-on Learning (2 Credits)	Dissertation/ Academic Project/ Entrepreneurship	Total Credits	Pool of GE to be offered for the students of other departments
	Credit Distribution: (4 * 3) = 12	**Credit Distribution: (4 * 2) = 8**	**Credit Distribution: (2*1) = 2**		**(12+8+2) = 22**	
Semester II	DSC-4: Optimization Techniques DSC-5: Queueing Theory DSC-6: Python Programming for Decision-Making	**Pool of DSE:** DSE-2(a): Applied Multivariate Analysis DSE-2(b): Financial Management DSE-2(c): Fundamentals of Managerial Economics DSE-2(d): Marketing Research DSE-2(e): Quality Management DSE-2(f): Soft Computing	SBC-2(a): Spreadsheet Modeling and Data Visualization SBC-2(b): Business Communication and Computational Analysis	NIL		GE-2(a): Queueing Theory GE-2(b): Marketing Research GE-2(c): Quality Management GE-2(d): Soft Computing

2nd year of PG curriculum structure for 2-year PG Program

Structure I (Level 6.5): PG Curriculum Structure with only course work

Semester	DSC (8 credits)	DSE-5, DSE-6, DSE-7 (12 credits) OR DSE-3, DSE-4 and GE-3 (12 credits)	Skill-based course /workshop/Specialized Laboratory/Internship/ Apprenticeship/Hands-on Learning (2credits)	Dissertation/ Academic Project/ Entrepreneurship	Total Credits	Pool of GE to be offered for the students of other departments
	Credit Distribution: (4 * 2) = 8	**Credit Distribution: (4 * 3) = 12**	**Credit Distribution: (2*1) = 2**		**(8+12+2) = 22**	
Semester III	DSC-7: Econometric Modeling and Forecasting DSC-8: Marketing Management	**Pool of DSE:** DSE-3(a): Bayesian Forecasting DSE-3(b): Data Warehousing and Data Mining DSE-3(c): Dynamic Optimization DSE-3(d): Health Care Management DSE-3(e): Marketing Analytics DSE-3(f): Multicriteria Decision-Making Techniques DSE-3(g): Quantitative Social Media Analysis DSE-3(h): Revenue Management DSE-3(i): Stochastic Modeling DSE-3(j): Supply Chain Management DSE-3(k): Warranty Modeling and Analysis	SBC-3: Operational Research Through Industry Workshops and Expert Interactions	NIL		GE -3(a): Marketing Management GE -3(b): Health Care Management GE -3(c): Revenue Management GE -3(d): Warranty Modeling and Analysis

2nd year of PG curriculum structure for 2-year PG Program

Structure I (Level 6.5): PG Curriculum Structure with only course work

Semester	**DSC** **(8 Credits)**	**DSE-8, DSE-9, DSE-10 (12 Credits)** **OR** **DSE-5, DSE-6 and GE-4 (12 Credits)**	**Skill-based course /workshop/Specialized Laboratory/Internship/ Apprenticeship/Hands-on Learning (2 Credits)**	**Dissertation/ Academic Project/ Entrepreneurship**	**Total Credits**	**Pool of GE to be offered for the students of other departments**
	Credit Distribution: **(4 * 2) = 8**	**Credit Distribution:** **(4 * 3) = 12**	**Credit Distribution:** **(2*1) = 2**		**(8+12+2) = 22**	
Semester IV	DSC-9: Reliability & Maintenance Theory DSC-10: Scheduling Techniques	**Pool of DSE:** DSE-4(a): Advanced Inventory Management DSE-4(b): Advanced Marketing Management DSE-4(c): Bayesian Reliability DSE-4(d): Logistics and Network Optimization DSE-4(e): Numerical Optimization DSE-4(f): Operational Research for Public Policy DSE-4(g): Pattern Recognition DSE-4(h): Portfolio Optimization DSE-4(i): Prognostics and Health Management of Systems DSE-4(j): Reliability Testing and Prediction DSE-4(k): Queueing Networks	SBC-4: Communicating Operational Research Models and Findings	NIL		GE - 4(a): Reliability and Maintenance Theory GE - 4(b): Scheduling Techniques

2nd year of PG curriculum structure for 2-year PG Program

Structure II (Level 6.5): PG Curriculum Structure with only course work + Research

Semester	DSC (8 Credits)	DSE-5 and DSE-6 (8 Credits) OR DSE-3 and GE-3 (8 Credits)	Skill-based course /workshop/Specialized Laboratory/Internship/ Apprenticeship/Hands-on Learning (2 Credits)	Dissertation/ Academic Project*/ Entrepreneurship/ (6 Credits)	Total Credits	Pool of GE to be offered for the students of other departments
	Credit Distribution: (4 * 2) = 8	**Credit Distribution: (4 * 2) = 8**	-	**Credit Distribution: 6**	**(8+8+6) = 22**	
Semester III	DSC-7: Econometric Modeling & Forecasting DSC-8: Marketing Management	**Pool of DSE:** DSE-3(a): Bayesian Forecasting DSE-3(b): Data Warehousing and Data Mining DSE-3(c): Dynamic Optimization DSE-3(d): Health Care Management DSE-3(e): Marketing Analytics DSE-3(f): Multicriteria Decision-Making Techniques DSE-3(g): Quantitative Social Media Analysis DSE-3(h): Revenue Management DSE-3(i): Stochastic Modeling DSE-3(j): Supply Chain Management DSE-3(k): Warranty Modeling and Analysis	NIL	**Outcomes as per University Guidelines**		GE -3(a): Marketing Management GE -3(b): Health Care Management GE -3(c): Revenue Management GE -3(d): Warranty Modeling and Analysis

***Academic Project will also include Industrial Project**

2nd year of PG curriculum structure for 2-year PG Program

Structure II (Level 6.5): PG Curriculum Structure with only course work + Research

Semester	DSC (8 Credits)	DSE-7 and DSE-8 (8 Credits) OR DSE-4 and GE-4 (8 Credits)	Skill-based course /workshop/Specialized Laboratory/Internship/ Apprenticeship/Hands-on Learning (2 Credits)	Dissertation/ Academic Project*/ Entrepreneurship/ (6 Credits)	Total Credits	Pool of GE to be offered for the students of other departments
	Credit Distribution: (4 * 2) = 8	**Credit Distribution: (4 * 2) = 8**	**-**	**Credit Distribution: 6**	**(8+8+6) = 22**	
Semester IV	DSC-9: Reliability & Maintenance Theory DSC-10: Scheduling Techniques	**Pool of DSE:** DSE-4(a): Advanced Inventory Management DSE-4(b): Advanced Marketing Management DSE-4(c): Bayesian Reliability DSE-4(d): Logistics and Network Optimization DSE-4(e): Numerical Optimization DSE-4(f): Operational Research for Public Policy DSE-4(g): Pattern Recognition DSE-4(h): Portfolio Optimization DSE-4(i): Prognostics and Health Management of Systems DSE-4(j): Reliability Testing and Prediction DSE-4(k): Queueing Networks	NIL	**Outcomes as per University Guidelines**		GE - 4(a): Reliability and Maintenance Theory GE - 4(b): Scheduling Techniques

***Academic Project will also include Industrial Project**

SYLLABI OF SEMESTERS III and IV

(STRUCTURE - I)

Discipline Specific Core - Semester III

DSC - 7: Econometric Modeling and Forecasting

DSC - 8: Marketing Management

DISCIPLINE SPECIFIC CORE
DSC - 7: ECONOMETRIC MODELING AND 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		
Econometric Modeling and Forecasting (DSC-7)	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- Introduce students to the principles, applications, and forecasting aspects of econometric modeling.
- Develop proficiency in multiple linear regression, logistic regression, time series analysis, and advanced econometric frameworks such as lag structures and simultaneous equation models.
- Enable students to apply econometric tools to real-world problems and accurately interpret empirical results.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Explain key concepts, assumptions, and challenges in econometric and time-series modeling, including models with quantitative and qualitative variables.
- Construct, interpret, and evaluate linear econometric and time-series models for forecasting and empirical analysis.
- Formulate and analyze advanced structures such as distributed-lag models and simultaneous-equation systems to address complex real-world applications.

Syllabus of DSC-7:

Unit I: Introduction **(8 hours)**
Types of data: Time series data, Cross-sectional data, Panel data, Importance of forecasting, Classification of forecast methods, Conceptual framework of a forecast system, Forecasting criteria.

Unit II: Regression Models and Analysis **(14 hours)**
Classical linear regression models (CLRMs): Multiple linear regression, Multiple and partial correlation coefficients, Violating the assumptions of CLRMs: Multi-collinearity, Heteroscedasticity, Autocorrelation, Non-linear regression models, Multivariate logistic regression model.

Unit III: Time Series Modeling and Analysis **(14 hours)**
Components of time series, Time series decomposition models, Exponential smoothing methods, Stationary and non-stationary time series, Consequence of non-stationarity, Detection of non-stationarity, Autoregressive (AR) time series models, Moving average (MA) models, ARMA models, ARIMA models, Box-Jenkins approach to forecasting.

Unit IV: Lag Models and Simultaneous Equation Models **(9 hours)**
Distributed lag models using Koyck transformation and Almon transformation, Simultaneous equations models: Basic definitions, Identification problem, Estimation, Forecasting from a simultaneous model.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Brockwell, P. J., & Davis, R. A. (2002). *Introduction to time series and forecasting*. New York: Springer.
2. Dougherty, C. (2011). *Introduction to econometrics* (4th ed.). New York: Oxford University Press.
3. Johnston, J. (1984). *Econometric methods* (3rd ed.). New York: Mc-Graw Hill.
4. Koutsoyiannis, A. (2001). *Theory of econometrics* (2nd ed.). New York: Palgrave Macmillan.
5. Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (1998). *Forecasting: methods and applications* (3rd ed.). New York: John Wiley & Sons Inc.
6. Montgomery, D. C., Jennings, C. L., & Kulahci, M. (2008). *Introduction to time series analysis and forecasting*. New York: Wiley-Blackwell.
7. Montgomery, D. C., Peck, E. A., & Vining, G. G. (2012). *Introduction to linear regression analysis* (5th ed.). New York: John Wiley & Sons Inc.

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

DISCIPLINE SPECIFIC CORE
DSC - 8: MARKETING 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		
Marketing Management (DSC - 8)	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart knowledge of introductory concepts and principles of Marketing.
- To make the students understand the theoretical basics of different market phenomena related to Customer Buying Behavior, Product and Brand Management, Pricing, Distribution and Promotional strategies.
- To impart the analytical thinking and nurture mathematical modeling concepts to solve real life management science problems.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Acquire analytical and decision-making skills applicable to business and management, including understanding marketing strategy formulation, implementation, and evaluation.
- Analyze market dynamics from producer and consumer perspectives to support strategic decision-making.
- Model innovation diffusion and apply quantitative techniques for sales forecasting of new products.

Syllabus of DSC - 8:

Unit I: Introduction to Marketing Management (8 hours)
Concept of Marketing and its role in Business and Public Organization, Role of Marketing Manager, Marketing Orientation, Marketing Mix-The traditional 4Ps, Modern components of the mix-the additional 3Ps, developing an effective marketing mix.

Unit II: Marketing Environment & Consumer Buying Behavior (11 hours)
Concept of perfect and imperfect competition, Factors influencing consumer buying behavior, External-Internal influence diffusion model for sales forecasting, Characteristics of a buyer, Difference between adopter and buyer, Adopter categorization.

Unit III: Marketing Mix-Product & Price (12 hours)
Product Life Cycle (PLC), Product line, Product mix strategies, New product development, Concept of multi-generations of products, Brand, Brand name selection, Brand equity, Brand switching analysis; Pricing: Elasticity Concept, marginal Analysis, Factors affecting pricing decision, Pricing methods, Optimal purchasing policies under fluctuating prices, Joint optimization of price, quality, and promotional effort.

Unit IV: Marketing Mix- Place and Promotion (14 hours)
Channels of distribution, Locating company's warehouses; Promotion Management: Promotional decisions in the presence of competition. Spatial Allocation of Promotional Effort, Media Allocation of Advertisement, Sales Response to Advertising in Presence of Competition.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Armstrong, G., Adam, S., Denize, S., & Kotler, P. (2018). *Principles of marketing* (7th ed.). Pearson Australia.
2. Kotler, P., Keller, K. L., Chernev, A., Sheth, J. N., & Shainesh, G. (2025). *Marketing management* (17th ed.). Pearson.
3. Curtis, T. (2008). *Marketing for engineers, scientists and technologists*. John Wiley & Sons.
4. Dowling, G. R. (2004). *The art and science of marketing: Marketing for marketing managers*. Oxford University Press.
5. Hooley, G. J., & Hussey, M. K. (1999). *Quantitative methods in marketing* (2nd ed.). International Thomson Business Press.

Suggested Readings:

1. Lilien, G. L., Kotler, P., & Moorthy, K. S. (2003). *Marketing models* (Eastern Economy ed.). Prentice-Hall of India.
2. Anand, A., Aggrawal, D., & Agarwal, M. (2019). *Market assessment with OR applications*. CRC press.

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

Discipline Specific Elective – Semester III

DSE - 3(a): Bayesian Forecasting

DSE - 3(b): Data Warehousing and Data Mining

DSE - 3(c): Dynamic Optimization

DSE - 3(d): Health Care Management

DSE - 3(e): Marketing Analytics

DSE - 3(f): Multicriteria Decision-Making Techniques

DSE - 3(g): Quantitative Social Media Analysis

DSE - 3(h): Revenue Management

DSE - 3(i) : Stochastic Modeling

DSE - 3(j) : Supply Chain Management

DSE - 3(k): Warranty Modeling and Analysis

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(a): BAYESIAN 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		
Bayesian Forecasting (DSE - 3(a))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To acquaint students with short-term Bayesian Forecasting methods which utilize data as well as subjective information.
- To teach students formulation of Dynamic Linear Models (DLMs), Noise Models-ARMA models in DLM form and Dynamic Generalized Linear Models (DGLMs) and forecasting.
- To teach applications of the methods taught using examples from industry and business fields

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Formulate DLM, Noise Models, and DGLMs model for forecasting using Bayesian approach.
- Know how to update models for forecasting.
- To perform diagnostics checks of how well the model to be used for forecasting fits the data.

Syllabus of DSE - 3(a):

Unit I: Introduction **(12 hours)**
Basics of Bayesian Statistics, MCMC (Markov Chain Monte Carlo) simulation; Time Series and its components; Dynamic Systems; Bayesian Approach to Forecasting.

Unit II: Dynamic Linear Model (DLM) **(12 hours)**
Model Form; Updating; Forward Intervention; Component Forms: Polynomial Trend Components, Seasonal Component Models, Harmonic Analysis, Regression Components; Superposition: Block Structured Models; Variance Learning; Forecast Monitoring; Error Analysis Applications.

Unit III: Noise Models **(12 hours)**
Basics of Time Series Models; ARMA models in DLM Form; Dynamic noise models as component DLMs; Non-linear learning problems; Applications.

Unit IV: Dynamic Generalized Linear Models **(9 hours)**
Introduction; Dynamic regression framework; DGLM updating; Step ahead forecasting and filtering; Linearization in the DGLM; Applications.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Broemeling, L.D. (2019). *Bayesian Analysis of Time Series*, CRC Press, Taylor and Francis Group, New York.
2. Pole, A. West, M., and Harrison, J. (1994). *Applied Bayesian Forecasting and Time Series Analysis*, Springer Science+ Business Media, B.V.
3. West, M. and Harrison, J. (1989). *Bayesian Forecasting and Dynamic Models*, Springer Science+ Business Media, New York.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(b): DATA WAREHOUSING AND DATA MINING

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		
Data Warehousing and Data Mining (DSE - 3(b))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To provide a comprehensive understanding of data warehousing concepts and data mining techniques for knowledge discovery.
- To emphasize on data preprocessing, modeling, and analysis of large datasets.
- To develop the ability to design and implement models that support effective data-driven decision-making.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Explain core concepts, architectures, and processes of data warehousing and data mining, including data preprocessing, cleaning, and transformation.
- Implement association, classification, prediction, and clustering algorithms on real-world datasets and evaluate the discovered patterns for effective decision-making.
- Design and develop complete data warehousing and data-mining solutions tailored to specific business or research applications.

Syllabus of DSE - 3(b):

Unit I: Introduction to Data Warehousing: **(10 hours)**
Introduction to Decision Support System, Data Warehousing and Online Analytical Processing, Data Warehouse: Basic Concepts, Data Extraction, Cleanup, and Transformation Tools, Data Warehouse Modeling: Data Cube, Schema and OLAP, Data Warehouse Design and Usage, Data Warehouse Implementation.

Unit II: Fundamentals of Data Mining: **(11 hours)**
Introduction to Data Mining, Knowledge Discovery in Databases (KDD), Data Mining Functionalities, Application and Issues in Data Mining. Data Exploration: Types of Attributes; Statistical Description of Data; Data Visualization; Measuring similarity and dissimilarity. Data Preprocessing, Data Cleaning, Data Integration and Transformation, Data Discretization, Normalization. Association Rule Mining: Market Basket Analysis, Frequent Item sets, Closed Item sets, and Association Rules; Efficient and Scalable Frequent Item-sets Mining Methods: The Apriori algorithm, Improving the Efficiency of Apriori algorithm, Mining Frequent item sets using vertical data formats; Mining closed and maximal patterns.

Unit III: Foundations of Classification and Prediction (12 hours)
Introduction to classification and prediction; issues regarding Classification and Prediction, interpretability, and scalability and data preparation. Decision tree induction, Bayesian classification (Naïve Bayes), Rule-based classification, k-Nearest Neighbor (KNN), Introduction to Regression Techniques for Prediction, Model evaluation and selection.

Unit IV: Essentials of Cluster Analysis (12 hours)
Introduction to cluster analysis; types of data and distance measures; partitioning methods (K-Means, K-Medians, K-Medoids); Hierarchical clustering (Agglomerative, Divisive, Linkage criteria); Clustering high-dimensional data, Cluster validation.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Adriaans, P., & Zantinge, D. (1996). *Data mining*. Addison-Wesley.
2. Berry, M. J. A., & Linoff, G. (2011). *Data mining techniques: For marketing, sales, and customer relationship management* (3rd ed.). John Wiley & Sons.
3. Berson, A., & Smith, S. J. (2007). *Data warehousing, data mining, and OLAP* (10th reprint). McGraw-Hill.
4. Gupta, G. K. (2014). *Introduction to data mining with case studies* (3rd ed.). PHI Learning.
5. Han, J., Kamber, M., & Pei, J. (2011). *Data mining: Concepts and techniques* (3rd ed.). Morgan Kaufmann.
6. Larose, D. T., & Larose, C. D. (2015). *Data mining and predictive analytics* (2nd ed.). Wiley-Blackwell.

Suggested Readings:

1. Fayyad, U. M., Piatetsky-Shapiro, G., Smyth, P., & Uthurusamy, R. (Eds.). (1996). *Advances in knowledge discovery and data mining*. MIT Press.
2. Tan, P.-N., Steinbach, M., Karpatne, A., & Kumar, V. (2018). *Introduction to data mining* (2nd ed.). Pearson.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(c): DYNAMIC 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		
Dynamic Optimization (DSE - 3(c))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To introduce the principle of optimality and multi-stage decision-making using discrete and continuous optimization problems.
- To formulate and solve dynamic programming and optimal control problems with applications across various domains.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Understand and explain the principle of optimality and foundational concepts of multi-stage decision-making, including discrete dynamic programming and the calculus of variations with necessary and sufficient conditions for extrema.
- Formulate and solve additive/multiplicative separable-return discrete models, continuous-time and discrete-time optimal control problems, and systems governed by maximum-principle-based optimality conditions.
- Apply dynamic programming, calculus of variations, and optimal control frameworks to real-world decision-making scenarios.

Syllabus of DSE - 3(c):

Unit I: Discrete Dynamic Programming (16 hours)
Principle of optimality and multi-stage decision processes, Bellman's equation and recursive formulation of dynamic optimization problems, Optimal policies for models with additive and multiplicative separable returns in objective and constraint functions, Sequential and non-sequential discrete optimization models, Dimensionality reduction technique, Applications in real-world problems across diverse application domains.

Unit II: Calculus of Variations (8 hours)
Introduction to calculus of variations, Formulation of variational problems, Classification of functionals and their stationary values, Euler-Lagrange equation and its applications to variational problems.

Unit III: Methods for Variational Problems (8 hours)
Weak and strong extrema, Necessary and sufficient conditions for optimality, Constrained variational problems, Lagrange multiplier method.

Unit IV: Optimal Control Theory (13 hours)
Fundamentals of optimal control theory, Mathematical models of continuous-time and discrete-time control systems, Pontryagin's maximum principle and necessary conditions for optimality, Transversality conditions, Applications of optimal control methods in marketing, inventory systems, production planning, and financial investment.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Chiang, A. C. (1999). *Elements of Dynamic Optimization*. Waveland Press Inc.
2. Sethi, S. P., & Thompson, G. L. (2005). *Optimal Control Theory-Applications to Management Science and Economics* (2nd Edition). Springer.
3. Seierstad, A., & Sydsaeter, K. (1987). *Optimal Control Theory with Economic Applications*. Elsevier.
4. Hillier, F. S., & Lieberman, G. J. (2025). *Introduction to Operations Research- Concepts and Cases* (12th Edition). Tata McGraw Hill (Indian print).

Suggested Readings:

1. Kaufmann, A., & Cruon, R. (1967). *Dynamic Programming*. Academic Press.
2. Kirk, D. (2004). *Optimal Control Theory- An Introduction*. Dover Publication.
3. MacCluer, C. R. (2005). *Calculus of Variations-Mechanics, Control Theory, and Other Applications*. Prentice Hall.
4. Taha, H. A. (2022). *Operations Research- An Introduction* (11th Edition). 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.

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(d): HEALTH CARE 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		
Health Care Management (DSE - 3(d))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To analyze healthcare systems and operational processes using quantitative methods and operations research tools.
- To model and solve real-world healthcare operations problems with a focus on improving efficiency, resource utilization, and decision-making quality.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Apply quantitative and optimization-based methods to formulate, analyze, and solve operational challenges within healthcare systems, considering real-world constraints and complexities.
- Use analytical and data-driven tools to design, test, and evaluate process-improvement across key healthcare functions such as patient flow, resource utilization, staffing, capacity planning, and supply chain management.
- Interpret and assess model outputs to understand the impact of operational decisions on service quality, system performance, and overall healthcare delivery effectiveness, including applications in emergency service planning.

Syllabus of DSE - 3(d):

Unit I: Health Care Systems and Services Management (13 hours)
Overview of global health and health care systems, Challenges in health care delivery across diverse populations, Effectiveness, efficiency, and value-based care, Decision-making frameworks in clinical and administrative settings, Distinctive characteristics of health care services and their operational implications, Principles and practices of health care services management.

Unit II: Forecasting in Health Care Operations (8 hours)
Health care demand forecasting, Capacity and resource planning, Forecast information for operational and strategic decision-making in health care services, Decision-making frameworks for service delivery, access, and system responsiveness improvements.

Unit III: Facility Planning in Health Care Operations **(9 hours)**
Location planning methods and their application to health care facility placement and accessibility, Location-allocation optimization models in health service: the p-median problem, location set covering problem, and maximal covering location problem, Facility layout design for enhancing workflow efficiency and patient care productivity, Analysis of basic layout design problems in clinical and support service environments.

Unit IV: **Resource and Operations Optimization in Health Care** **(15 hours)**
Workload management approaches for clinical, diagnostics and support services, Staffing and scheduling strategies to manage patient demand, and service coverage, Productivity assessment and performance indicators in health care operations, Optimization models for resource allocation and capacity planning, Principles of inventory management for pharmaceuticals, consumables, and medical supplies, Queuing theory applications for patient-flow, waiting time and service-time analysis, Introduction to simulation modeling for evaluating operational alternatives and improving health care service delivery.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Anupindi, R., Chopra, S., Deshmukh, S., Van Mieghem, J., & Zemel, E. (2012). *Managing Business Process Flows* (3rd Edition). Prentice Hall.
2. Brandeau, M. L., Sainfort, F., & Pierskalla, W. P. (2005). *Operations Research and Health Care: A Handbook of Methods and Applications*. Springer.
3. Denton, B.T. (2013). *Handbook of Healthcare Operations Management: Methods and Applications*. Springer.
4. Ozcan, Y. A. (2017). *Quantitative Methods in Health Care Management: Techniques and Applications*. John Wiley & Sons.
5. Rahman, S. U., & Smith, D. K. (2000). Use of location-allocation models in health service development planning in developing nations. *European Journal of Operational Research,* 123(3), 437-452. Elsevier.
6. Research articles in journals and reports from the Census of India, WHO, NSSO, UNICEF, etc.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(e): MARKETING ANALYTICS

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		
Marketing Analytics (DSE - 3(e))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To provide conceptual understanding of marketing analytics and its strategic role in decision making.
- To develop the ability to analyze customer data for segmentation, targeting, and loyalty modeling.
- To apply predictive and prescriptive models for customer valuation, product bundling, and advertising decisions.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Understand the concepts, scope, and applications of marketing analytics and apply analytical models for customer segmentation, targeting, and loyalty analysis.
- Evaluate customer preferences, value, and product-bundling opportunities using quantitative and data-driven tools.
- Utilize analytical insights to enhance marketing performance, optimize decisions, and improve customer engagement.

Syllabus of DSE - 3(e):

Unit I: Foundations of Marketing Analytics (8 hours)
Conceptual introduction to marketing analytics, Evolution, scope, and significance of analytics in marketing, Data for marketing analytics: sources, types, and data quality, Problem-solving and decision-making models in marketing.

Unit II: Customer Segmentation and Targeting (12 hours)
Prospecting and targeting the right customers, Market segmentation using analytical models: Logistic Regression, Neural Networks, Decision Trees, Predicting customer response through RFM analysis, Introduction to customer loyalty: 3Rs of loyalty, Modeling loyalty using Confirmatory Factor Analysis (CFA), Structural Equation Modeling (SEM), and Partial Least Squares (PLS).

Unit III: Understanding Customer Preferences and Value (10 hours)
Choice modeling and customer preference estimation, Concept and benefits of product bundling, Market Basket Analysis and association rules, Customer Lifetime Value (CLV) estimation, Allocating marketing resources between acquisition and retention strategies.

Unit IV: Digital and Network-Based Marketing Analytics (15 hours)
Online advertising analytics: display ads, search ads (PPC), and media selection models, Next-product-to-buy and recommendation systems, Learning from customer purchases and ratings, Cross-selling and up-selling strategies, Social network analytics: network structure, random and regular networks, diffusion over networks, Text analytics, online user content analysis, and mobile commerce insights.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Winston W.L. (2020). *Marketing analytics: Data-driven techniques with Microsoft Excel*. John Wiley & Sons, New Jersey.
2. Sorger S. (2013). *Marketing Analytics: Strategic Models and Metrics*. Admiral Press.
3. Hemann, C. and K. Burbary (2018). *Digital marketing analytics: Making sense of consumer data in a digital world*, Pearson Education.
4. Mike Grigsby (2016). *Advanced Customer Analytics-Targeting, Valuing, Segmenting and Loyalty Techniques*, Kogan pages.

Suggested Readings:

1. Wedel, M., & Kamakura, W. A. (2012). *Market Segmentation: Conceptual and Methodological Foundations*. Springer.
2. Tandon, A., & Aggarwal, A. G. (2023). *Consumer behaviour in digital markets*, Macmillan.
3. Shmueli, G., Bruce, P. C., Patel, N. R., & Yahav, I. (2017). *Data Mining for Business Analytics: Concepts, Techniques, and Applications in R*. Wiley.
4. Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate Data Analysis***.** Pearson Education.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(f): MULTICRITERIA DECISION-MAKING TECHNIQUES

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		
Multicriteria Decision-Making Techniques (DSE - 3(f))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To develop a strong conceptual and mathematical foundation in Multicriteria Decision-Making (MCDM) models and methodologies.
- To equip students with the ability to formulate, model, and analyze complex decision-making problems involving multiple conflicting criteria and alternatives.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Formulate and structure complex decision problems involving multiple conflicting criteria, and operational constraints across diverse application domains.
- Apply appropriate MCDM and performance evaluation techniques, including efficiency assessment models to analyze and compare decision alternatives or decision-making units (DMUs).
- Utilize MCDM frameworks to generate evidence-based insights that support informed policy, engineering, and management decisions.

Syllabus of DSE - 3(f):

Unit I: Multi-Objective Optimization **(10 hours)**
Concept of trade-offs and conflicting objectives, Pareto optimality, Proper pareto optimality, Lexicographic optimality, Optimality conditions, Weighted sum method, ε-Constraint method.

Unit II: **Performance and Priority Evaluation Techniques** **(13 hours)**
Data envelopment analysis: input and output-oriented formulations, efficient and inefficient DMUs, slack analysis and performance targets for inefficient DMUs, graphical analysis for efficient frontier, Charnes, Cooper and Rhodes model for constant returns to scale, Banker, Charnes and Cooper model for variable returns to scale, Analytic hierarchy process: construction of pairwise comparison matrices, ranking and weighting information using eigen vector method and approximation methods, extension to group decision-making.

Unit III: Attribute Utility Models (10 hours)
Utility and scoring models: construction of single-attribute and multi-attribute utility functions, additive and multiplicative utility formulations, scaling and normalization of criteria, weighted linear and multiplicative scoring models, Ranking and evaluating alternatives: Simple additive weighting method, Weighted product method, Multi-attribute utility method.

Unit IV: Compensatory Models (12 hours)
Distance-based and compromise ranking methods, Principle of compromise solutions, Positive and negative ideal solutions, TOPSIS method: normalization, weight assignment, ideal and anti-ideal determination, separation measures, relative closeness coefficient, VIKOR method: utility and regret measures, ranking index, decision strategy for compromise solutions.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Triantaphyllou, E. (2000). *Multi-Criteria Decision-Making Methods: A Comparative Study*. Springer.
2. Ramanathan, R. (2003). *Introduction to Data Envelopment Analysis: A Tool for Performance Measurement.* Sage Publications Pvt Ltd.
3. Brunelli, M. (2015). *Introduction to the Analytic Hierarchy Process.* Springer.
4. Steuer, R. E. (1986). *Multiple Criteria Optimization-Theory, Computation, and Application.* Wiley Series in Probability and Mathematical Statistics-Applied, Wiley.
5. Tzeng, G.-H., & Huang, J.-J. (2011). *Multiple Attribute Decision Making: Methods and Applications.* CRC Press.
6. Research articles in journals from SCI/SCIE/SCOPUS Indexed Journals.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(g): QUANTITATIVE SOCIAL MEDIA 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		
Quantitative Social Media Analysis (DSE - 3(g))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To introduce the basic concepts of Social Media Analysis,
- To teach the important characteristics of various social media
- To teach the students about mathematical models for information diffusion

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Understand the principles of marketing with a focus on social media marketing, including measurement of content characteristics.
- Explain foundational concepts of social media analysis using social network theory.
- Mathematically model information diffusion and epidemic dynamics and understand mechanisms of viral marketing.

Syllabus of DSE-3(g):

Unit I: Introduction to Social Media **(10 hours)**
Fundamental concepts of the Social Media Research Domain and related Areas, Content Characteristics, Content Dynamics, and User Dynamics, Introduction to Network Concepts and Random Network Models

Unit II: Social Media Analytics **(13 hours)**
Fundamentals of Social Media Analytics-Network Building and Visualization techniques, Introduction to Community Detection and Link Prediction methods, Social Media Monitoring, Social Media Advertising Analytics

Unit III: Information Diffusion **(10 hours)**
Quantification of the virality of information in online Social Networks, Probabilistic Models of Information Flow, Cascading Behavior, and epidemic modeling to understand the spread of information, Understanding Over the top (OTT) platforms and Freemium as an advertising strategy for OTT platforms

Unit IV: YouTube: An Effective Social Media **(12 hours)**
View count model for viewership classification & prediction, and further classification of viewers based on the time of their activation. Modeling the growing YouTube Viewership and fitting these dynamic models to various extracted datasets for the viewership growth Pattern, dynamic internet market size-based modeling for YouTube videos

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Chakraborty, T. (2021). *Social network analysis*. Wiley.
2. Zafarani, R., Abbasi, M. A., & Liu, H. (2017). *Social media mining: An introduction*. Cambridge University Press.
3. Barabási, A.-L**.** (2017). *Network science*. Cambridge University Press.
4. HYang, S., Keller, F. B., & Zheng, L. (2016). *Social network analysis: Methods and examples*. SAGE Publications, Inc.
5. Research articles from journals of national and international repute.

Suggested Readings:

1. Borgatti, S. P., Everett, M. G., Johnson, J. C., & Agneessens, F. (2022). *Analyzing social networks using R*. SAGE Publications.
2. Aggrawal, N., & Anand, A**.** (2022). *Social networks: Modelling and analysis*. CRC Press.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(h): REVENUE 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		
Revenue Management DSE - 3(h)	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:

- To examine the fundamental principles of pricing and the concept of revenue management as an emerging paradigm in managerial practices across various industries.
- To analyse capacity allocation and price-based revenue management models, along with the optimization techniques employed in revenue management.
- To evaluate the application of revenue management across different industry sectors and identify the key factors influencing its successful implementation.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Formulate and revise pricing and product availability decisions across multiple selling channels to maximize a firm's profitability.
- Develop, analyse, and solve revenue optimization models and apply them effectively within organizational settings.
- Identify and leverage opportunities for revenue optimization across diverse business environments.

Syllabus of DSE-3(h):

Unit I: Introduction to Pricing and Revenue Management (6 hours)
History of Pricing and Revenue Optimization. Strategies of Price optimization. Conceptual framework of Revenue Management. Booking controls. Revenue management system. Factors affecting revenue management. Role of revenue management in various industries.

Unit II: Price Optimization (15 hours)
Basic Price Optimization: The Price-Response Function, measure of Price sensitivity, Price Response with Competition. Price Differentiation: The Economics and Tactics of Price Differentiation, Calculating Differentiated Prices, Price Differentiation and Consumer Welfare. Optimal Pricing with Supply Constraint, Market Segmentation and Supply Constraints, Variable Pricing.

Unit III: Capacity Allocation in RM **(15 hours)**
Capacity Allocation Models: Littlewood's two class model, capacity allocation for multiple classes (n-class model), expected marginal seat revenue models (EMSR-a and EMSR-b). Capacity allocation for multiple resources: Network Revenue Management and its applicability. Network RM via Linear Programming approach. Overbooking models: overbooking based on service criteria, economic criteria (simple risk-based booking limit model). Overbooking problem with multiple products/classes and multiple resources.

Unit IV: Price based RM and Applications **(9 hours)**
Applicability of dynamic pricing. Markdown pricing. Promotion based pricing. Customized pricing. Implementing RM in various industries - hotels, car rentals, manufacturing, retailing, sports centre, online travel portals, restaurants, freight, railways. Factors critical in making a RM system effective

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Cross, G. R. (1997). *Revenue management: Hard-core tactics for market domination*: by Robert G. Cross. Broadway Books, 1540 Broadway, New York, NY 10036, 1997.
2. Lilien, G. L., Kotler, P., & Moorthy, K. S. (1995). *Marketing models*. Prentice Hall.
3. Nagle, T. T., & Müller, G. (2017). *The strategy and tactics of pricing: A guide to growing more profitably*. Routledge.
4. Phillips, R. L. (2005). *Pricing and revenue optimization*. Stanford University Press.
5. Sfodera, F. (Ed.). (2006). *The spread of yield management practices: the need for systematic approaches*. Springer Science & Business Media.
6. Talluri, K. T., & Van Ryzin, G. J. (2006). *The theory and practice of revenue management* (Vol. 68). Springer Science & Business Media.
7. Yeoman, I., & McMahon-Beattie, U. (Eds.). (2004*). Revenue management and pricing: Case studies and applications*. Cengage Learning EMEA.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(i): STOCHASTIC MODELING

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		
Stochastic Modeling (DSE - 3(i))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- Understand the principles, structure, and classification of stochastic processes and their role in modeling dynamic systems, with emphasis on discrete- and continuous-time models such as Markov and Poisson processes.
- Construct and evaluate stochastic models including random walks, martingales, diffusion-type processes, and Brownian motion for applications in finance, engineering, and related fields.
- Extend basic Markov models to semi-Markov and renewal processes and analyze their relevance in operational and real-world systems.

Learning Outcomes:

Upon successful completion, students will be able to:
- Classify stochastic processes by time parameter, state space, and dependence structure, and formulate DTMC and CTMC models to derive transient and steady-state distributions.
- Apply and simulate random walk, martingale, semi-Markov, and renewal models to evaluate probabilistic behavior, reliability, and operational efficiency.
- Develop and implement diffusion-based models, including Brownian motion and geometric Brownian motion, for dynamic and financial forecasting.

Syllabus of DSE - 3(i):

Unit I: Introduction to Stochastic Processes (6 hours)
Definition of stochastic process; Classification into discrete and continuous time; Concept of state space, index set, and sample paths; Stationary and non-stationary processes; Basic ideas of probabilistic evolution and dependence; Markov property and memoryless processes; Examples of stochastic processes in operational research, finance, and engineering.

Unit II: Discrete-Time Stochastic Models (13 hours)
Discrete-Time Markov Chains (DTMC) – definition, transition probability matrix, Chapman–Kolmogorov equations, classification of states (transient, recurrent, periodic, absorbing), limiting and stationary distributions, ergodic chains, mean recurrence times; Random walks — simple, symmetric and asymmetric, boundary crossing problems, gambler's ruin problem and applications; Martingales – definition, properties, examples, and applications in fair game and financial modeling.

Unit III: Continuous-Time Stochastic Models (13 hours)
Poisson Process – definition, event occurrence times, superposition and splitting mechanisms, compound Poisson process; Continuous-Time Markov Chains (CTMC) – transition rate matrix, Kolmogorov forward and backward equations, birth-death processes, transient analysis and limiting behavior; Renewal process – basic definition, concept and simple applications.

Unit IV: Advanced Stochastic Models (13 hours)
Semi-Markov processes – definition, transition probability functions, limiting behavior, relation to Markov and renewal processes, applications in system performance analysis; Martingales – revisited with continuous-time perspective; Brownian motion – definition, properties, continuity, first passage times; Geometric Brownian Motion (GBM) – definition, stochastic differential form, properties, and applications in finance and dynamic system modeling.

Tutorial component (if any) - Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Blanco, L., Arunachalam, V., & Dharmaraja, S. (2016). *Introduction to Probability and Stochastic Processes with Applications.* Wiley (Asian Edition).
2. Çinlar, E. (2013). *Introduction to Stochastic Processes.* Dover Publications. Karlin, S., & Taylor, H. M. (1975). *A First Course in Stochastic Processes.* Academic Press.
3. Kulkarni, V. G. (2016). *Modeling and Analysis of Stochastic Systems* (3rd Edition). CRC Press (Taylor & Francis Group).
4. Medhi, J. (2009). *Stochastic Processes* (3rd Edition). New Age International Publishers.
5. Ross, S. M. (1995). *Stochastic Processes* (2nd Edition). John Wiley & Sons.
6. Ross, S. M. (2014). *Introduction to Probability Models* (11th Edition). Academic Press (Elsevier).
7. Taylor, H. M., & Karlin, S. (2010). *An Introduction to Stochastic Modeling* (4th Edition). Academic Press (Elsevier).

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(j): SUPPLY CHAIN 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		
Supply Chain Management (DSE - 3(j))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- Impart the knowledge of concepts related to supply chain management with emphasis on informed decision-making in real world supply chain decisions.
- Analyze and formulate mathematical and analytical models to optimize supply chain networks, facility locations, and distribution strategies.
- Analyze and model sustainable, resilient, and global supply chain networks.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Define key supply chain terminologies and explain how strategic, tactical, and operational decisions influence overall performance.
- Use performance indicators, supply chain drivers, and quantitative analysis to support decision-making, identify inefficiencies, and assess supplier selection and allocation strategies through multi-criteria frameworks.
- Design resilient and optimized supply chain networks that integrate risk management, sustainability practices, and environmental considerations.

Syllabus of DSE - 3(j):

Unit I: Fundamentals of Supply Chain Management (10 hours)
Introduction to Supply Chain Management- Scope & Objectives; Evolution, Components of the Supply Chain and Supply-chain as flows, Supply Chain as a Decision System: Importance of Supply Chain Decisions, Decision Phases; Supply Chain vs. Logistics; Supply Chain Strategy and Performance, Supply Chain Drivers and Metrics, Assessing and Managing Supply Chain Performance, Role of Optimization in Supply Chain Planning, Introduction to Supply Chain Analytics: descriptive, predictive, prescriptive frameworks.

Unit II: Network Design, Facility Location and Distribution Decisions (12 hours)
Introduction to Supply Chain Network Design. Factors Influencing Network Configuration; Inbound and Outbound Logistics ,roles, flows and integration with network design, Distribution Network Types and Design Options, Framework for Network Design Decisions and Mathematical Modeling, Supply Chain Network Optimization: Facility Location Fundamentals, Warehouse Location, Distribution Planning, Location-Distribution with Dedicated Warehouses Continuous Location Models, The

capacitated plant location Network Optimization Model: With single sourcing, with simultaneous plants and warehouses location and distribution decisions.

Unit III: Supply Chain Planning, Coordination, and Supplier Selection (12 hours)
Role of Demand Forecasting in Supply Chain Management, Alternatives for Managing Demand and Supply, Tabular and Optimization Models for Aggregate Planning with Linear and Non-Linear Programming, Ratchet Effect; Bullwhip Effect, Coordination in Supply chain, Supplier selection problem: stages, criteria, and strategies. Multi-criteria supplier evaluation methods, Mathematical models for supplier allocation, Multi-Objective Supplier Allocation Model.

Unit IV: Sustainable, Resilient, and Global Supply Chain Optimization (11 hours)
Global supply chain, Reverse supply chain, closed loop supply chain, green supply chain, Sustainability in supply chain, Lean Manufacturing and Agile supply chain, Risk in Supply Chain, Ripple Effect, Disruption in Supply Chain, Managing and Modeling Supply Chain Resilience.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Ravindran, A. R., Warsing, D. P., Jr., & Griffin, P. M. (2023). *Supply chain engineering: Models and applications* (2nd edition). CRC Press
2. Chopra, S., & Meindl, P. (2020). *Supply chain management: Strategy, planning & operation* (7th edition). Pearson.
3. Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., & Shankar, R. (2019). *Designing and managing the supply chain: Concepts, strategies, and case studies* (4th edition). McGraw Hill Education (India).
4. Ivanov, D. (2021). *Introduction to supply chain resilience: Management, modelling, technology*. Springer Nature.

Suggested Readings:

1. Christopher, M. (2023). *Logistics & supply chain management* (6th edition). Pearson Education.
2. Shapiro, J. F. (2006). *Modeling the supply chain* (2nd edition). Duxbury Press.
3. Gupta, S. M. (Ed.). (2013). *Reverse supply chains: Issues and analysis*. CRC Press.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(k): WARRANTY MODELING AND 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		
Warranty Modeling and Analysis (DSE - 3(k))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To explain warranty as a critical element in the marketing of products – a concept that is important to both the seller and the buyer of virtually any consumer or commercial product.
- To teach methodology behind formulation of one-dimensional, two-dimensional and extended warranties.
- To teach how to analyze warranty data.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Formulate warranty policies.
- Deal with cost and optimization problems from the manufacturers' and buyers' point of view.
- Analyze warranty data.

Syllabus of DSE - 3(k):

Unit I: Introduction **(12 hours)**
Products: Product Classification, Product Performance, Product Warranty, Product Reliability; Classification of Warranties: One-Dimensional (1-D) Warranties, Two-Dimensional (2-D) Warranties, Group Warranties, Reliability Improvement Warranties, Extended Warranties; Warranty Data Collection: Types & Sources of Data, Warranty Claims Data.

Unit II: **Models & Techniques** **(12 hours)**
Cost Models for 1-D Warranties- Per Unit Cost: FRW Policy, Renewing FRW Policy, Non-Renewing PRW Policy, Life Cycle Cost Analysis per unit sale: Non-renewing FRW Policy, Non-Renewing PRW Policy. Cost Models for 2-D Warranties – Modeling Failures & Claims (Type-I usage), Warranty Cost Analysis unit – Different Approaches.

Unit III: Extended Warranties **(12 hours)**
System Degradation & Maintenance, Modelling & Analysis of Degradation and Maintenance (1-D Formulations), Extended & Maintenance Service Contracts Cost Analysis – Cost Analysis of Base Warranty, Cost Analysis of Extended Warranty, Cost Analysis of Maintenance Service Contracts, Basics of Lease Contracts.

Unit IV: Warranty Data Analysis and management **(9 hours)**
Analysis of 1-D data using competing risk models, Acceleration Failure Time Models, Proportional Hazard (P-H) models, Regression Models; Analysis of 2-D data – based on usage rate, composite scale, bivariate model formulation, forecasting expected warranty claim; use of warranty data for improving current products and operations, role of warranty data in new product development.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Blischke, W. R, Karim. M. R. and Murthy, D.N.P (2001). *Warranty Data Collection and Analysis*, Springer-Verlag London Ltd.
2. Blischke W. R. and Murthy, D.N.P. (1994). *Warranty cost analysis*. New York: Marcel Dekker.
3. Murthy, D.N.P. and Jack, N. (2014). *Extended Warranties, Maintenance Service, and Lease Contract: Modeling and Analysis for Decision Making*, Springer
4. Thomas, M. U. (2006). *Reliability and Warranties: Methods for Product Development and Quality Improvement*, CRC Taylor and Francis Group, New York.
5. Yang, G. (2007). *Life Cycle Reliability Engineering*, John Wiley & Sons, Inc., Hoboken, New Jersey.

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

Skill Based Course – Semester III

SBC – 3

Operational Research Through Industry Workshops and Expert Interactions

SKILL BASED COURSE
SBC - 3: OPERATIONAL RESEARCH THROUGH INDUSTRY WORKSHOPS AND EXPERT INTERACTIONS

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		
Operational Research Through Industry Workshops and Expert Interactions (SBC - 3)	2	0	0	2	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- Expose students to practical OR applications through industry workshops and interactions.
- Enable students to understand real-world OR models and their interpretation.
- Develop analytical and decision-making skills relevant to industry contexts.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Explain key OR modelling ideas used in industry settings.
- Prepare structured summaries reflecting understanding of OR applications.
- Compare theoretical OR models with practical implementations in organizations.

Practical component/tasks: **(60 hours)**

The following practical activities shall be carried out by the students:

1. Attend an OR-focused workshop/seminar (in online/offline mode).
2. Prepare a reflective note on OR applications in various sectors.
3. Present connections between workshop learning and OR theory.
4. Compare classroom OR models with real OR implementations.
5. Solve case-based OR problem such as scheduling, routing, resource allocation, managerial discretions, etc.
6. Perform simulation exercises using real/simulated datasets.
7. Analyze real industrial case studies where OR tools drive operational decisions.
8. Write structured summaries of workshop/seminar attended.
9. Evaluate data availability, organizational challenges and outcome validity.

Essential Readings:

1. Hillier & Lieberman (2021). *Introduction to Operations Research*. McGraw-Hill.
2. Winston, Wayne L. (2020). *Operations Research: Applications and Algorithms*. Cengage.
3. Taha, Hamdy A. (2017). *Operations Research: An Introduction*. Pearson.

Suggested Readings:

1. Ravindran, A. et al. (2013). *Operations Research: Principles and Practice*. Wiley.
2. Sharma, J.K. (2017). *Operations Research: Theory and Applications*. Macmillan.
3. Selected INFORMS Case Studies and industry white papers.

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

Generic Elective - Semester III

GE - 3(a): Marketing Management

GE - 3(b): Health Care Management

GE - 3(c): Revenue Management

GE - 3(d): Warranty Modeling and Analysis

GENERIC ELECTIVE
GE - 3(a): MARKETING 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		
Marketing Management (GE - 3(a))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart knowledge of introductory concepts and principles of Marketing.
- To make the students understand the theoretical basics of different market phenomena related to Customer Buying Behavior, Product and Brand Management, Pricing, Distribution and Promotional strategies.
- To impart the analytical thinking and nurture mathematical modeling concepts to solve real life management science problems.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Acquire analytical and decision-making skills applicable to business and management, including understanding marketing strategy formulation, implementation, and evaluation.
- Analyze market dynamics from producer and consumer perspectives to support strategic decision-making.
- Model innovation diffusion and apply quantitative techniques for sales forecasting of new products.

Syllabus of GE - 3(a):

Unit I: Introduction to Marketing Management (8 hours)
Concept of Marketing and its role in Business and Public Organization, Role of Marketing Manager, Marketing Orientation, Marketing Mix-The traditional 4Ps, Modern components of the mix-the additional 3Ps, developing an effective marketing mix.

Unit II: Marketing Environment & Consumer Buying Behavior (11 hours)
Concept of perfect and imperfect competition, Factors influencing consumer buying behavior, External-Internal influence diffusion model for sales forecasting, Characteristics of a buyer, Difference between adopter and buyer, Adopter categorization.

Unit III: Marketing Mix-Product & Price (12 hours)
Product Life Cycle (PLC), Product line, Product mix strategies, New product development, Concept of multi-generations of products, Brand, Brand name selection, Brand equity, Brand switching analysis; Pricing: Elasticity Concept, marginal Analysis, Factors affecting pricing decision, Pricing methods, Optimal purchasing policies under fluctuating prices, Joint optimization of price, quality, and promotional effort.

Unit IV: Marketing Mix- Place and Promotion (14 hours)
Channels of distribution, Locating company's warehouses; Promotion Management: Promotional decisions in the presence of competition. Spatial Allocation of Promotional Effort, Media Allocation of Advertisement, Sales Response to Advertising in Presence of Competition.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Armstrong, G., Adam, S., Denize, S., & Kotler, P. (2018). *Principles of marketing* (7th ed.). Pearson Australia.
2. Kotler, P., Keller, K. L., Chernev, A., Sheth, J. N., & Shainesh, G. (2025). *Marketing management* (17th ed.). Pearson.
3. Curtis, T. (2008). *Marketing for engineers, scientists and technologists*. John Wiley & Sons.
4. Dowling, G. R. (2004). *The art and science of marketing: Marketing for marketing managers*. Oxford University Press.
5. Hooley, G. J., & Hussey, M. K. (1999). *Quantitative methods in marketing* (2nd ed.). International Thomson Business Press.

Suggested Readings:

1. Lilien, G. L., Kotler, P., & Moorthy, K. S. (2003). *Marketing models* (Eastern Economy ed.). Prentice-Hall of India.
2. Anand, A., Aggrawal, D., & Agarwal, M. (2019). *Market assessment with OR applications*. CRC press.

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

GENERIC ELECTIVE
GE - 3(b): HEALTH CARE 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		
Health Care Management (GE - 3(b))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:

- To analyze healthcare systems and operational processes using quantitative methods and operations research tools.
- To model and solve real-world healthcare operations problems with a focus on improving efficiency, resource utilization, and decision-making quality.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Apply quantitative and optimization-based methods to formulate, analyze, and solve operational challenges within healthcare systems, considering real-world constraints and complexities.
- Use analytical and data-driven tools to design, test, and evaluate process-improvement across key healthcare functions such as patient flow, resource utilization, staffing, capacity planning, and supply chain management.
- Interpret and assess model outputs to understand the impact of operational decisions on service quality, system performance, and overall healthcare delivery effectiveness, including applications in emergency service planning.

Syllabus of GE - 3(b):

Unit I: Health Care Systems and Services Management (13 hours)
Overview of global health and health care systems, Challenges in health care delivery across diverse populations, Effectiveness, efficiency, and value-based care, Decision-making frameworks in clinical and administrative settings, Distinctive characteristics of health care services and their operational implications, Principles and practices of health care services management.

Unit II: Forecasting in Health Care Operations (8 hours)
Health care demand forecasting, Capacity and resource planning, Forecast information for operational and strategic decision-making in health care services, Decision-making frameworks for service delivery, access, and system responsiveness improvements.

Unit III: Facility Planning in Health Care Operations **(9 hours)**
Location planning methods and their application to health care facility placement and accessibility, Location-allocation optimization models in health service: the p-median problem, location set covering problem, and maximal covering location problem, Facility layout design for enhancing workflow efficiency and patient care productivity, Analysis of basic layout design problems in clinical and support service environments.

Unit IV: **Resource and Operations Optimization in Health Care** **(15 hours)**
Workload management approaches for clinical, diagnostics and support services, Staffing and scheduling strategies to manage patient demand, and service coverage, Productivity assessment and performance indicators in health care operations, Optimization models for resource allocation and capacity planning, Principles of inventory management for pharmaceuticals, consumables, and medical supplies, Queuing theory applications for patient-flow, waiting time and service-time analysis, Introduction to simulation modeling for evaluating operational alternatives and improving health care service delivery.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Anupindi, R., Chopra, S., Deshmukh, S., Van Mieghem, J., & Zemel, E. (2012). *Managing Business Process Flows* (3rd Edition). Prentice Hall.
2. Brandeau, M. L., Sainfort, F., & Pierskalla, W. P. (2005). *Operations Research and Health Care: A Handbook of Methods and Applications*. Springer.
3. Denton, B.T. (2013). *Handbook of Healthcare Operations Management: Methods and Applications*. Springer.
4. Ozcan, Y. A. (2017). *Quantitative Methods in Health Care Management: Techniques and Applications*. John Wiley & Sons.
5. Rahman, S. U., & Smith, D. K. (2000). Use of location-allocation models in health service development planning in developing nations. *European Journal of Operational Research, 123(3), 437-452.* Elsevier.
6. Research articles in journals and reports from the Census of India, WHO, NSSO, UNICEF, etc.

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

GENERIC ELECTIVE
GE - 3(c): REVENUE 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		
Revenue Management GE - 3(c)	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To examine the fundamental principles of pricing and the concept of revenue management as an emerging paradigm in managerial practices across various industries.
- To analyse capacity allocation and price-based revenue management models, along with the optimization techniques employed in revenue management.
- To evaluate the application of revenue management across different industry sectors and identify the key factors influencing its successful implementation.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and revise pricing and product availability decisions across multiple selling channels to maximize a firm's profitability.
- Develop, analyse, and solve revenue optimization models and apply them effectively within organizational settings.
- Identify and leverage opportunities for revenue optimization across diverse business environments.

Syllabus of GE - 3(c):

Unit I: Introduction to Pricing and Revenue Management (6 hours)
History of Pricing and Revenue Optimization. Strategies of Price optimization. Conceptual framework of Revenue Management. Booking controls. Revenue management system. Factors affecting revenue management. Role of revenue management in various industries.

Unit II: Price Optimization (15 hours)
Basic Price Optimization: The Price-Response Function, measure of Price sensitivity, Price Response with Competition. Price Differentiation: The Economics and Tactics of Price Differentiation, Calculating Differentiated Prices, Price Differentiation and Consumer Welfare. Optimal Pricing with Supply Constraint, Market Segmentation and Supply Constraints, Variable Pricing.

Unit III: Capacity Allocation in RM **(15 hours)**
Capacity Allocation Models: Littlewood's two class model, capacity allocation for multiple classes (n-class model), expected marginal seat revenue models (EMSR-a and EMSR-b). Capacity allocation for multiple resources: Network Revenue Management and its applicability. Network RM via Linear Programming approach. Overbooking models: overbooking based on service criteria, economic criteria (simple risk-based booking limit model). Overbooking problem with multiple products/classes and multiple resources.

Unit IV: Price based RM and Applications **(9 hours)**
Applicability of dynamic pricing. Markdown pricing. Promotion based pricing. Customized pricing. Implementing RM in various industries - hotels, car rentals, manufacturing, retailing, sports centre, online travel portals, restaurants, freight, railways. Factors critical in making a RM system effective

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Cross, G. R. (1997). *Revenue management: Hard-core tactics for market domination*: by Robert G. Cross. Broadway Books, 1540 Broadway, New York, NY 10036, 1997.
2. Lilien, G. L., Kotler, P., & Moorthy, K. S. (1995). *Marketing models*. Prentice Hall.
3. Nagle, T. T., & Müller, G. (2017). *The strategy and tactics of pricing: A guide to growing more profitably*. Routledge.
4. Phillips, R. L. (2005). *Pricing and revenue optimization*. Stanford University Press.
5. Sfodera, F. (Ed.). (2006). *The spread of yield management practices: the need for systematic approaches*. Springer Science & Business Media.
6. Talluri, K. T., & Van Ryzin, G. J. (2006). *The theory and practice of revenue management* (Vol. 68). Springer Science & Business Media.
7. Yeoman, I., & McMahon-Beattie, U. (Eds.). (2004*). Revenue management and pricing: Case studies and applications*. Cengage Learning EMEA.

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GENERIC ELECTIVE
GE - 3(d): WARRANTY MODELING AND 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		
Warranty Modeling and Analysis (GE - 3(d))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To explain warranty as a critical element in the marketing of products – a concept that is important to both the seller and the buyer of virtually any consumer or commercial product.
- To teach methodology behind formulation of one-dimensional, two-dimensional and extended warranties.
- To teach how to analyze warranty data.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate warranty policies.
- Deal with cost and optimization problems from the manufacturers' and buyers' point of view.
- Analyze warranty data.

Syllabus of GE - 3(d):

Unit I: Introduction **(12 hours)**
Products: Product Classification, Product Performance, Product Warranty, Product Reliability; Classification of Warranties: One-Dimensional (1-D) Warranties, Two-Dimensional (2-D) Warranties, Group Warranties, Reliability Improvement Warranties, Extended Warranties; Warranty Data Collection: Types & Sources of Data, Warranty Claims Data.

Unit II: **Models & Techniques** **(12 hours)**
Cost Models for 1-D Warranties- Per Unit Cost: FRW Policy, Renewing FRW Policy, Non-Renewing PRW Policy, Life Cycle Cost Analysis per unit sale: Non-renewing FRW Policy, Non-Renewing PRW Policy. Cost Models for 2-D Warranties – Modeling Failures & Claims (Type-I usage), Warranty Cost Analysis unit – Different Approaches.

Unit III: Extended Warranties **(12 hours)**
System Degradation & Maintenance, Modelling & Analysis of Degradation and Maintenance (1-D Formulations), Extended & Maintenance Service Contracts Cost Analysis – Cost Analysis of Base Warranty, Cost Analysis of Extended Warranty, Cost Analysis of Maintenance Service Contracts, Basics of Lease Contracts.

Unit IV: Warranty Data Analysis and management **(9 hours)**
Analysis of 1-D data using competing risk models, Acceleration Failure Time Models, Proportional Hazard (P-H) models, Regression Models; Analysis of 2-D data – based on usage rate, composite scale, bivariate model formulation, forecasting expected warranty claim; use of warranty data for improving current products and operations, role of warranty data in new product development.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Blischke, W. R, Karim. M. R. and Murthy, D.N.P (2001). *Warranty Data Collection and Analysis*, Springer-Verlag London Ltd.
2. Blischke W. R. and Murthy, D.N.P. (1994). *Warranty cost analysis*. New York: Marcel Dekker.
3. Murthy, D.N.P. and Jack, N. (2014). *Extended Warranties, Maintenance Service, and Lease Contract: Modeling and Analysis for Decision Making*, Springer
4. Thomas, M. U. (2006). *Reliability and Warranties: Methods for Product Development and Quality Improvement*, CRC Taylor and Francis Group, New York.
5. Yang, G. (2007). *Life Cycle Reliability Engineering*, John Wiley & Sons, Inc., Hoboken, New Jersey.

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

Discipline Specific Core - Semester IV

DSC - 9: Reliability & Maintenance Theory

DSC - 10: Scheduling Techniques

DISCIPLINE SPECIFIC CORE
DSC - 9: RELIABILITY AND MAINTENANCE 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		
Reliability and Maintenance Theory (DSC - 9)	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To introduce the key concepts and methods in reliability engineering.
- To teach reliability modelling of systems with different configurations along with optimal reliability allocation and redundancy techniques.
- To teach concept of repair and its impact on the performance of the system along with formulation of maintenance and replacement policies.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Develop reliability models for non-repairable systems under various configurations and perform reliability assessment, including optimal system design through reliability and redundancy allocation.
- Model repairable systems using renewal processes, non-homogeneous Poisson processes, and state-space methods.
- Formulate appropriate system maintenance strategies to enhance overall system performance and reliability.

Syllabus of DSC - 9:

Unit I: System Reliability (9 hours)
Basics of Reliability. Classes of life distributions based on Notions of Ageing. System Reliability: Reliability of Series, Parallel, Standby, k-out-of-n, Series-Parallel, Parallel -Series configurations and Bridge Structure. Multi-state System-Series and Parallel systems.

Unit II: Optimal Reliability Design Techniques (10 hours)
Optimal Reliability Allocation, Redundancy Allocation Problem: Formulation of optimal redundancy problem with a single restriction for a series system.

Unit III: Repairable System Modeling (16 hours)

Types of Repair, Availability theory: Types of Availability measures; Perfect Repair Models: Introduction to Renewal theory, Types of Renewal Processes and their Asymptotic Properties, Reward Renewal Processes Minimal Repair Models: Introduction to Non Homogenous Poisson Process, Power Law Model; State Space Methods: Markovian approach for reliability/ availability analysis of repairable series and parallel systems, systems with dependent components, and various types of standby systems, System Performance Characteristics, Load-Sharing Systems, Semi-Markovian Approach for one unit system reliability analysis.

Unit IV: Maintenance Policies (10 hours)

Corrective Maintenance; Preventive Maintenance, Age Replacement Policy: cost type criterion, Block Replacement Policy: Cost-type criterion. Preventive Maintenance: one-unit system with repair, Maintenance policies with minimal repairs.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Barlow, R. E., & Proschan, F. (1975). *Statistical theory of reliability and life testing*. Holt, Rinehert & Winston Inc.
2. Cox, D. R. (1967). *Renewal theory*. London: Methuen.
3. Gertsbakh, I. (2013). *Reliability theory with applications to preventive maintenance*. Springer.
4. Kapur, P. K., Kumar, S., & Garg, R. (1999). *Contributions to hardware and software reliability*. Singapore: World Scientific.
5. Kuo, W., & Zuo, M. J. (2003). *Optimal reliability modeling: principles and applications*. John Wiley & Sons.
6. Mitov, K. V., & Omey, E. (2014). *Renewal processes*. Springer. Nakagawa, T. (2005). Maintenance theory on reliability. London: Springer-Verlag.
7. Pham, H. (2003). *Handbook of reliability engineering*. London: Springer-Verlag. Rau, J. G. (1970). Optimization and probability in systems engineering. V.N. Reinhold Co.
8. Rausand, M., & Hoyland, A. (2003). *System reliability theory: models, statistical methods, and applications*. John Wiley & Sons.

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

DISCIPLINE SPECIFIC CORE
DSC - 10: SCHEDULING TECHNIQUES

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Prerequisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Scheduling Techniques (DSC - 10)	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart a deep understanding of the theories and concepts underlying various scheduling problems in Operations Research.
- To develop knowledge of key areas such as network flow models, project management, and sequencing problems.
- To enhance the ability to apply scheduling and optimization techniques to real-world operational and managerial contexts.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and analyze mathematical models for network flow problems and project networks with deterministic and probabilistic activity durations and critically evaluate project schedules including cost–time trade-offs.
- Manage resources efficiently under operational and project constraints to improve overall system performance.
- Optimize job allocation in multi-machine production systems to minimize total elapsed time.

Syllabus of DSC - 10:

Unit I: Network Scheduling: Fundamentals and Solution Methodology (10 hours)
Graphs and networks, Path, Cycle, Tree and Cut in a network, Node-arc incidence matrix, Excess capacity matrix, Flows in networks, Max flow- Min cut theorem, Flow augmenting path. Linear programming formulation of Maximal flow problem, Minimum cost flow problem, and Multi-commodity flow problem.

Unit II: Network Models and Applications (10 hours)
Shortest path problem, Travelling Salesman problem, Minimum spanning tree, Capacitated Network flow problem, Transhipment problem, Facility location models: Mathematical modelling and solution methodology.

Unit III: Project Scheduling **(15 hours)**
Project management with known and probabilistic activity times (CPM & PERT), constructing project networks: Gantt chart, Activity on arrow/Activity on node, Various types of floats and their significance, Project crashing, Linear programming formulation of Project crashing, Project updation, Resource constrained project scheduling: Resource levelling & Resource smoothing.

Unit IV: Theory of Sequencing **(10 hours)**
Flow-shop and Job-shop problems, Johnsons' optimality rule for a general Flow-shop problem, Parallel processing, General n/m Job-shop integer programming formulation.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Ahuja, R. K., Magnanti, T. L., Orlin, J. B., & Reddy, M. R. (1995). *Applications of network optimization. Handbooks in Operations Research and Management Science*. Elsevier.
2. Baker, K. R., & Trietsch, D. (2019). *Principles of sequencing and scheduling*. John Wiley & Sons Inc.
3. Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2010). *Linear programming and network flows*. John Wiley & Sons.
4. Elmaghraby, S. E. (1977). *Activity networks: Project planning and control by network models*. John Wiley & Sons Inc.
5. Ford, L. R., & Fulkerson, D. R. (2015). *Flows in networks*. Princeton University Press.
6. Jensen, P. A., & Barnes, J. W. (1980). *Network flow programming*. John Wiley & Sons Inc.
7. Wiest, J. D., & Levy, F. K. (1977). *Management guide to PERT/CPM: with GERT/PDM/DCPM and other networks*. Prentice-Hall of India Pvt. Ltd.

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

Discipline Specific Elective – Semester IV

DSE - 4(a): Advanced Inventory Management

DSE - 4(b): Advanced Marketing Management

DSE - 4(c): Bayesian Reliability

DSE - 4(d): Logistics and Network Optimization

DSE - 4(e): Numerical Optimization

DSE - 4(f): Operational Research for Public Policy

DSE - 4(g): Pattern Recognition

DSE - 4(h): Portfolio Optimization

DSE - 4(i): Prognostics and Health Management of Systems

DSE - 4(j): Reliability Testing and Prediction

DSE - 4(k): Queueing Networks

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(a): ADVANCED INVENTORY 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		
Advanced Inventory Management (DSE - 4(a))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- Equip students with advanced inventory control techniques and their practical implementation in real-world business scenarios.
- Provide an in-depth understanding of classical and extended inventory management models, including multi-echelon systems.
- Develop students' ability to model, analyze, and apply both deterministic and stochastic inventory models for effective decision-making.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Demonstrate a comprehensive understanding of classical inventory models, their extensions, and advanced frameworks, and apply quantitative tools to analyze inventory costs and determine optimal policies.
- Explain the structure and functioning of multi-echelon inventory systems and their relevance in both academic and practical settings.
- Understand and apply the principles of Material Requirements Planning (MRP) and key concepts in materials management.

Syllabus of DSE - 4(a):

Unit I: Overview of EOQ Model and its Extensions (12 hours)
Types of inventory models. Probabilistic Reorder Point Inventory Models with and without Lead Time. Two bin(S, s) Inventory Policy. Distribution Free Analysis. Minimax Solution of Inventory Models.

Unit II: Multi-echelon Inventory Systems (15 hours)
Two-warehousing Problems in Inventory management. Capacity Expansion Models. Periodic and Continuous Review models. Inventory Management of Deteriorating Items. EOQ with time value of money. Inventory Control under Inflationary Conditions. EOQ with imperfect quality. EOQ with trade credit.

Unit III: Inventory Control in Supply-Chains **(9 hours)**
Material Requirement Planning (MRP): Approaches and benefits of MRP. Introduction to MRP I and MRP II. Inputs to an MRP system. Dependent Demand, Bill of Material, Determining net Requirement, Time Phased Order Point.

Unit IV: Material Management **(9 hours)**
System approach to material management, Importance of Material Management. Value Analysis: Objectives, techniques and application of value analysis. Purchasing Function. Codification: Brisch and Kodak systems. Standardization, Classification, Simplification.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Arrow, K. J., Karlin, S., & Scarf, H. E. (1958). *Studies in the mathematical theory of inventory and production*. Stanford University Press.
2. Axsäter, S. (2015). *Inventory control*. Springer.
3. Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.
4. Muckstadt, J.A., & Sapra, A. (2010). Principles *of Inventory Management: When You Are Down to Four, Order More*. Springer-Verlag.
5. Naddor, E. (1966). *Inventory Systems*. Wiley
6. Ploss, G.W. (1985). *Production and Inventory Control-Principle and Techniques.* 2^{nd} Edition. Prentice Hall.
7. Porteus, E. L. (2002). *Foundations of stochastic inventory theory*. Stanford University Press.
8. Schwarz, L. B. (1981). *Multi-level production/inventory control systems: theory and practice*. North Holland.
9. Sherbrooke, C. C. (2004). *Optimal inventory modeling of systems: multi-echelon techniques.* 2^{nd} Edition. Springer.
10. Zipkin, H. P. (2000). *Foundations of Inventory Systems*. McGraw-Hill.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(b): ADVANCED MARKETING 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		
Advanced Marketing Management (DSE - 4(b))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart knowledge of advanced concepts of Marketing Management.
- To make the students understand mathematical modeling skills to bring in an understanding of scientific management in the entire system.
- To impart analytical thinking and nurture managerial discretion in students.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Understand advanced principles of management and the theoretical foundations of new product management.
- Describe concepts related to successive generational modeling in marketing and their strategic implications.
- Gain insight into mathematical models used for analyzing markets and improving managerial decision-making.

Syllabus of DSE - 4(b):

Unit I: Understanding Advancements in Market (10 hours)
Theoretical modeling in marketing, the complexity of marketing models, Management Science and Market Response Models; Defining Consumer Behavior, Evolution of consumer behavior as a field of study and its relationship with Marketing, Mathematical models for consumer buying behavior, om ni-channel marketing concept, the buying decision process: the five stages Model, Adoption Process, Uni-modal and multi-modal diffusion models, Market Extensions models and Refinements.

Unit II: Launch and Management of New Market Offerings (10 hours)
Introduction to Infusion process, New Product Decisions: From ideation to pre-launch of new products, Post launch activities, Understanding the launch phenomenon, the launch cycle, Product Line Decisions, Successive Generations: Concept and Modeling Framework.

Unit III: Generic Marketing Strategies (12 hours)
Defining Market Segmentation, Bases of segmentation, evaluation and targeting marketing segments and related mathematical models, Brand Positioning and differentiation, Stochastic Models of Brand Choice, Introduction to the concept of Warranty Reserves and Analysis

Unit IV: Some Related Modeling Concepts (13 hours)
Understanding market behavior using transition time-based modeling, impact of uncertainty on diffusion dynamics, role of Epidemic Modeling Framework in adoption process, Game theory models for promotional effort, effect of Advertising, and other related Mathematical Models, role of convolution process to understand diffusion process.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Lilien, G. L., Kotler, P., & Moorthy, K. S. (2003). *Marketing models* (Eastern Economy ed.). Prentice-Hall of India.
2. Lilien, G. L., & Rangaswamy, A. (2004). *Marketing engineering: Computer-assisted marketing analysis and planning* (Revised 2nd ed.). Trafford Publishing.
3. Kahn, K. B. (2006). *New product forecasting: An applied approach.* M. E. Sharpe.
4. Montgomery, D. B., & Urban, G. L. (1969). *Management science in marketing*. Prentice-Hall.
5. Research articles from journals of national and international repute.

Suggested Readings:

1. Kotler, P., Keller, K. L., Chernev, A., Sheth, J. N., & Shainesh, G. (2025). *Marketing Management* (17th ed.). Pearson.
2. Murdick, R. G. (1971). *Mathematical models in marketing*. Intext Educational Publishers.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(c): BAYESIAN RELIABILITY

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		
Bayesian Reliability (DSE - 4(c))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To acquaint the students with the performance evaluation of complex devices produced by technological advances using Bayesian reliability analyses.
- To explain maintenance policies using Bayesian approach
- To explain Bayesian Reliability Demonstration Testing (BRDT) that enables demonstrating whether a specified reliability has been achieved in a newly designed component or system and Bayesian Hierarchical models that help predicting reliability of new products.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Evaluate system reliability measures using Bayesian approach.
- Evaluate availability measures of repairable systems
- Learn benefits of applying BRDT and Bayesian Hierarchical models.

Syllabus of DSE - 4(c):

Unit I: System Reliability **(12 hours)**
Basics of Reliability Engineering and Basics of Bayesian Statistics; Coherent Systems, Basic System Configurations: Reliability Block Diagrams and systems' reliability evaluation, Assignment of Prior Distributions: Component Level Priors, System Level Prior, Reliability evaluation of a series system; Reliability evaluation of a parallel system, Reliability design of a parallel system with identical components; Reliability evaluation of k-out-of-n System , Stress-Strength k-out-of-n system.

Unit II: Availability of Maintained Systems **(12 hours)**
Availability Measures, General Failure Times/General Repair Times: Component Availability, Series System Availability; Exponential Failure Times/Exponential Repair Times: Component Availability, Series System Availability, Parallel System Availability, Standby System Availability; Exponential Failure Times / General Repair Times; Periodic Maintenance in Redundant System.

Unit III: Bayesian Reliability Demonstration Testing **(12 hours)**
Classical Zero-failure Test Plans for Substantiation Testing; Classical Zero-failure Test Plans for Reliability Testing; Bayesian Zero-failure Test Plan for Substantiation Testing; Bayesian Zero-failure Test Plan for Reliability Testing.

Unit IV: Bayesian Hierarchical Modeling (9 hours)
Introduction; Bayesian Hierarchical Binomial Model; Separate One-level Bayesian Models Bayesian Hierarchical Model; Bayesian Hierarchical Weibull Model.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Bansal, A. K. (2007). Bayesian Parametric Inference, Narosa Publishing House, New Delhi.
2. Berger, J. (1985). Statistical Decision Theory and Bayesian Analysis. New York: Springer-Verlag.
3. Martz, H.F. and Waller, R. A. (1982). Bayesian Reliability Analysis, John Wiley & Sons Inc., New York.
4. Liu, Y. and Abeyratne, A.I. (2019). Practical Applications of Bayesian Reliability, John Wiley & Sons Inc., Hoboken, USA.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(d): LOGISTICS AND NETWORK 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		
Logistics and Network Optimization (DSE - 4(d))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To develop conceptual and mathematical understanding of classical and contemporary optimization models applied to logistics, transportation, routing, and network systems.
- To enable students to model and solve complex logistics and distribution problems involving multiple locations, vehicles, routes, and network structures.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and analyze logistics, routing, and network optimization problems with multiple objectives, constraints and decision variables.
- Apply appropriate optimization techniques, including network models, distribution models, and vehicle routing to real-world logistics and transportation systems.
- Use mathematical programming and computational tools to design and evaluate efficient logistics and distribution systems.

Syllabus of DSE - 4(d):

Unit I: Distribution System Models **(8 hours)**
Structure and components of distribution systems, Mathematical formulation of single and multi-stage distribution models, Representation and roles of warehouses and depots, Performance measures and bottleneck identification.

Unit II: Multi-Index Logistics Models **(10 hours)**
Multi-index logistics models: motivation and structure, Representation of logistics decisions using multi-dimensional indices such as location, vehicle, and route, Exact and Heuristic solution methods, Applications including multi-level, multi-product, and multi-modal logistics systems.

Unit III: **Vehicle Routing** **(12 hours)**
Vehicle routing: capacitated, multiple-depot, time-window, and heterogeneous-fleet variants, Heuristic methods including the Nearest Neighbor and Clarke-Wright Savings algorithms, Modeling and analysis of real-world routing applications in logistics, distribution, and transportation planning.

Unit IV: Network Optimization (15 hours)
Foundations of constrained network flow problems: structure, assumptions, objectives and constraints, Formulation of network flow models as single and multi-objective mathematical programming problems, Optimality and duality principles, Flow-augmentation and residual-network concepts, Optimality tests, Network Simplex method, Degeneracy.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Ahuja, R. K., Magnanti, T. L., & Orlin, J. B. (1993). *Network Flows: Theory, Algorithms, and Applications.* Prentice Hall.
2. Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2010). *Linear Programming and Network Flows* (4th Edition). Wiley.
3. Daskin, M. S. (2013). *Network and Discrete Location: Models, Algorithms, and Applications* (2nd Edition). Wiley.
4. Toth, P., & Vigo, D. (2014). *Vehicle Routing: Problems, Methods, and Applications* (2nd Edition). SIAM.
5. Sinha, K. C., & Labi, S. (2007). *Transportation Decision Making*. John Wiley & Sons, Inc.
6. Research articles in journals from SCI/SCIE/SCOPUS Indexed Journals.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(e): NUMERICAL 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		
Numerical Optimization (DSE - 4(e))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To understand the theoretical foundations and computational techniques of numerical optimization, including linear fractional programming, separable programming, nonlinear optimization, and bi-level programming models.
- To learn appropriate solution methods for modelling and solving real-world constrained optimization problems across diverse application domains.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and solve optimization problems using linear fractional and separable programming techniques.
- Apply solution methods for constrained nonlinear optimization problems, including penalty, barrier, and feasible-direction techniques, and implement complementary pivot algorithm for linear and quadratic programming problems.
- Formulate and solve bi-level programming problems using Karush–Kuhn–Tucker (KKT) conditions and appropriate solution methods.

Syllabus of DSE - 4(e):

Unit I: Linear Fractional Programming (8 hours)
Linear fractional programming: concept, formulation, properties of optimal solution, Simplex method, Charnes-Cooper variable transformation method, Applications in production, finance, and portfolio selection.

Unit II: Nonlinear Programming Methods (8 hours)
Constrained nonlinear programming problems: Penalty function method, Barrier function method, Frank-Wolfe method, Reduced gradient method, Convex simplex method.

Unit III: Separable and Complementarity Programming (16 hours)
Separable programming: concept and structure of separable functions, piecewise linear approximation of nonlinear functions, adjacency condition, formulation of approximate linear programming model, Modified Simplex method, convergence, Linear complementarity problem: formulation, properties, relationship to linear and quadratic programming, Complementary pivot algorithm and its variants.

Unit IV: Bi-Level Programming (13 hours)
Bi-level programming: concept and hierarchical structure of leader–follower optimization problem, Formulation of linear bi-level programming models, existence and optimality of solutions, KKT optimality conditions, Solution algorithms for linear bi-level programming problems, Applications in economics and transportation.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. BajaIinov, E. B. (2003). *Linear-fractional Programming: Theory, Methods, Applications, and Software*. Springer.
2. Bazara, M. S., Sherali, H. D., & Shetty, C. M. (2006). *Nonlinear Programming-Theory and Algorithms* (3rd Edition). John Wiley & Sons (Indian print).
3. Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical Optimization with Applications*. Narosa Publishing House.
4. Dempe, S. (2002). *Foundations of Bilevel Programming.* Kluwer Academic Publishers.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(f): OPERATIONAL RESEARCH FOR PUBLIC POLICY

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		
Operational Research for Public Policy (DSE - 4(f))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To provide a conceptual understanding of the role of OR techniques in policy formulation, evaluation, and effective resource allocation through optimization and decision models.
- To utilize data-driven decision-making for evidence-based governance and improved policy planning.
- To develop understanding of ethical, participatory, and stakeholder-oriented aspects of policy modelling.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Model and analyze public policy problems using OR techniques and evaluate policy alternatives through cost–benefit and multi-criteria decision models.
- Use data and quantitative methods to support evidence-based public decision-making.
- Interpret model outcomes to promote transparent, equitable, and accountable policymaking.

Syllabus of DSE - 4(f):

Unit I: Operations Research and Policy Modelling Foundations (10 hours)

Scope and relevance of Operational Research (OR) in public policy; evolution of OR from hard quantitative optimization to soft, participatory, and systems-based approaches; distinction between hard OR models (mathematical programming, optimization) and soft OR methods (problem structuring, cognitive mapping, and stakeholder engagement). Decision-making under certainty, risk, and uncertainty; systems approach to governance and analytical frameworks for public decision processes; Cost–Benefit and Cost-Effectiveness Analysis; Social Welfare Optimization and ethical dimensions in policy evaluation.

Unit II: Resource Allocation and Infrastructure Planning (11 hours)

Optimization for public resources allocation; prioritization of public investments, budgeting and project selection; network and facility location models for transportation, housing, and essential services; operational research tools for urban infrastructure and smart-city logistics; community-based and decentralized OR approaches in planning and development policy.

Unit III: OR Applications in Health, Environment, and Social Sectors (12 hours)
Applications of OR in healthcare planning, pandemic management, and vaccination logistics; queuing and service models for hospitals, e-governance, and transport systems; system dynamics and simulation for environmental management, resource sustainability, and climate policy; Multi-Criteria Decision Analysis for social programme evaluation and policy comparison; optimization and modelling for disaster response, waste management, and emission control; integrated use of OR techniques for achieving social and environmental objectives.

Unit IV: Data, Behavioral Decision Making, and Governance Analytics (12 hours)
Data-driven modelling and behavioral approaches to decision-making in governance; integration of quantitative analysis with behavioral insights for improved policy design; predictive modelling for policy forecasting and electoral analysis; voter segmentation, turnout analysis, and campaign optimization; use of AI, data analytics, and digital platforms in evidence-based governance; ethical, transparency, and accountability considerations in analytical modelling; OR contributions to sustainable, inclusive, and citizen-centered policy frameworks.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Loucks, D. P. (2022). *Public systems modeling: Methods for identifying and evaluating alternative plans and policies* (International Series in Operations Research & Management Science, Vol. 318). Springer.
2. Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill.
3. Drèze, J., & Stern, N. (1990). *Policy Reform: Concepts, Analysis, and Implementation*. Oxford University Press.
4. Johnson, M. P. (Ed.). (2012). *Community-based operations research.* Springer.
5. Saltelli, A., & Di Fiore, M. (Eds.). (2023). *The politics of modelling: Numbers between science and policy.* Oxford University Press.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(g): PATTERN RECOGNITION

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		
Pattern Recognition (DSE - 4(g))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart knowledge of concepts related to pattern recognition, including classification techniques, feature selection, and feature extraction methods.
- To develop practical skills in applying clustering and optimization algorithms for analysing data patterns, improving decision-making, and solving real-world problems efficiently.

Learning Outcomes:

Upon successful completion of this course, the student will be able to:
- Explain foundational principles of pattern recognition, including classification, feature engineering, clustering, and dimensionality reduction techniques.
- Apply linear and non-linear classifiers along with PCA, LDA, ICA, DFT, and DWT for supervised learning, and analyze clustering algorithms such as DBSCAN, DENCLUE, Spectral Clustering, and Vector Quantization for pattern discovery.
- Demonstrate practical proficiency in computational and statistical tools for real-world pattern recognition applications.

Syllabus of DSE - 4(g):

Unit I: Classification Techniques (12 hours)
Introduction to Pattern Classification; Linear classifiers and discriminant functions; Decision boundaries and hyperplanes; Measure of error of misclassification and Linear Programming (LPP) formulation; Single-layer Perceptron algorithm; Logistic regression; Support Vector Machines (SVM): Hard margin and Soft margin classifiers; Kernel-based nonlinear SVM; Nonlinear classifiers: Polynomial classifiers, Multi-layer Perceptron (MLP); Ensemble classifiers.

Unit II: Feature Selection Techniques (12 hours)
Filter and Wrapper methods, Univariate Feature Selection Methods: Fisher Discriminant Ratio, Pearson correlation, Mutual Information, Multivariate selection methods: Divergence, Chernoff Bound and Bhattacharya distance measures, Scatter Matrices, Minimum-redundancy-maximum-relevance criterion, Feature Subset Selection.

Unit III: Feature Extraction and Transform-Based Modeling (11 hours)
Introduction to feature extraction and dimensionality reduction; Singular Value Decomposition, Principal Component Analysis, Linear Discriminant Analysis, Independent Component Analysis, Transform-based methods: Discrete Fourier Transform and Discrete Wavelet Transform.

Unit IV: Advanced Clustering and Optimization-Based Learning Methods (10 hours)
Density based algorithm for large data sets (DBSACN, DENCLUE), Mixture Decomposition schemes, Vector Quantization, Spectral Clustering based on Graph network, and Competitive Learning algorithms, Cluster Validation.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Theodoridis, S., & Koutroumbas, K. (2008). *Pattern recognition* (4th edition). Academic Press.
2. Duda, R. O., Hart, P. E., & Stork, D. G. (2020). *Pattern classification* (2nd edition). Wiley India.
3. Xu, R., & Wunsch, D. C. (2008). *Clustering*. John Wiley & Sons.

Suggested Readings:

1. Fukunaga, K. (1990). *Introduction to statistical pattern recognition* (2nd edition). Academic Press.
2. Bishop, C. M. (2006). *Pattern recognition and machine learning*. Springer.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(h): PORTFOLIO 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		
Portfolio Optimization (DSE - 4(h))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To build a strong conceptual foundation in portfolio theory, emphasizing risk-return trade-off, diversification, and optimal asset allocation strategies.
- To develop analytical and computational skills for portfolio optimization modelling and performance evaluation.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Explain and analyze the concepts of risk, return, and diversification, and evaluate their significance in designing and managing effective investment portfolios.
- Apply analytical and computational techniques along with portfolio optimization models using alternative risk measures and multi-factor asset-pricing frameworks to construct, optimize, and support informed investment decisions.
- Quantitatively assess portfolio performance using evaluation metrics such as the Sharpe ratio, Jensen's Alpha, and Treynor ratio.

Syllabus of DSE - 4(h):

Unit I: Fundamentals of Portfolio Theory (13 hours)
Portfolio management, Asset classes, Risk and return, Expected value, Variance and covariance of asset returns, Diversification and its role in risk reduction, Short selling, Liquidity and Market impact, Mean–variance analysis, Efficient frontier, Alternative risk measures, Applications of hedging in managing portfolio risk.

Unit II: Portfolio Optimization and Evaluation (14 hours)
Markowitz mean-variance model and the Two-fund theorem, Portfolio optimization using alternative risk measures: mean absolute deviation, mean semi-absolute deviation, value at risk, and conditional value at risk, Portfolio allocation based on marginal risk contribution and implied returns, Portfolio performance evaluation using Jensen's Alpha, Sharpe ratio, and Treynor ratio.

Unit III: Capital Asset Pricing **(9 hours)**
Capital asset pricing model: assumptions, derivation, and expected return-beta relationship, Security market line, Capital market line, One-fund theorem, Arbitrage pricing theory.

Unit IV: Index models **(9 hours)**
Index models and multi-factor models for explaining asset returns, Applications of factor models in risk assessment and portfolio construction, Comparison of index-based portfolio approaches with the Markowitz mean–variance framework.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Bartholomew-Biggs, M. (2005). *Nonlinear Optimization with Financial Applications*. Springer.
2. Gupta, P., Mehlawat, M. K., Inuiguchi, M., & Chandra, S. (2014). *Fuzzy Portfolio Optimization: Advances in Hybrid Multi-Criteria Methodologies*. Springer.
3. Lhabitant, F. S. (2007). *Handbook of Hedge Funds*. Wiley.
4. Luenberger, D. G. (2014). *Investment Science* (2nd Edition). Oxford University Press Inc.
5. Markowitz, H. M. (2000). *Mean-Variance Analysis in Portfolio Choice and Capital Markets*. Wiley.

Suggested Readings:

1. Marrison, C. (2002). *The Fundamentals of Risk Measurement*. McGraw Hill.
2. Prigent, J. L. (2007). *Portfolio Optimization and Performance Analysis*. CRC Press.
3. Reilly, F. K., & Brown, K. C. (2012). *Investment Analysis and Portfolio Management* (10th Edition). Cengage Learning.
4. Roman, S. (2004). *Introduction to the Mathematics of Finance: From Risk Management to Options Pricing*. Springer.
5. Sharpe, W. F. (2000). *Portfolio Theory and Capital Markets*. McGraw Hill.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(i): PROGNOSTICS AND HEALTH MANAGEMENT OF SYSTEMS

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		
Prognostics and Health Management of Systems (DSE - 4(i))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To introduce Prognostics and Health Management (PHM) as a multifaceted discipline that protects components and products, by avoiding unanticipated problems that can lead to performance deficiencies and adverse effects on safety.
- To introduce prognostics as the process of predicting a system's performance.
- To acquaint students with Condition-Based Maintenance (CBM) as a cost-effective maintenance strategy, which helps perform maintenance only when needed, and helps keep complex engineering systems safe.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Use model-based Prognostics Methods for predicting Remaining Useful Life (RUL) of the system.
- Use data-driven based Prognostics Methods for predicting RUL of the system.
- Use condition-based maintenance strategies for health management of systems.

Syllabus of DSE - 4(i):

Unit I: Introduction **(12 hours)**
Reliability and Prognostics, Historical Background, Prognostics and Health Management (PHM) Applications, Benefits of Prognostics: Benefits in Life-Cycle Cost, Benefits in System Design and Development; Benefits in Production, Benefits in System Operation, Benefits in Logistics Support and Maintenance, PHM Metrics; Sensor Systems for PHM.

Unit II: **Model-Based Prognostics** **(9 hours)**
PoF (Physics of Failure) Prognostics: Introduction, Failure Modes, Mechanisms, and Effects Analysis (FMMEA), Nonlinear Least Squares Method; Markov Chain Monte Carlo Sampling Method, Particle Filter Method.

Unit III: Data-Driven Prognostics **(9 hours)**
Introduction, Gaussian Process Regression, Neural Network: Feedforward Neural Network Model; Concept of Remaining Useful Life (RUL); Applications: Battery Degradation Prognostics, Crack Propagation Prognostics; Comparison Between Physics-Based and Data-Based Prognostics.

Unit IV: **System Health Management** **(15 hours)**
Types of Maintenance; Preventive versus condition-based maintenance; P-F (Prevention- Failure) Curve; Bathtub Curve; Condition-Based Maintenance (CBM) Strategies: Single-Unit systems, Multi-Component Systems; RUL and Dynamic Maintenance Policy.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Kim, N-H, An, Dow, and Choi, J-H (2017). *Prognostics and Health Management of Engineering Systems: An Introduction*. Springer International Publishing, Switzerland.
2. Pecht, M.G. (2008*). Prognostics and Health Management of Electronics*- John Wiley & Sons Inc. Publications, USA.
3. Pecht, M.G. and Kang, M. (2018). *Prognostics and Health Management of Electronics-Fundamentals, Machine Learning, and the Internet of Things*. John Wiley & Sons Ltd. UK.
4. Goodman, D., Hofmeister, K.P., and Szidarovszky, F. (2019). *Prognostics and Health Management - A Practical Approach to Improving System Reliability Using Condition-Based Data*. John Wiley & Sons Ltd. UK.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(j): RELIABILITY TESTING AND PREDICTION

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		
Reliability Testing and Prediction (DSE - 4(j))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To explain a product's life cycle and concept of reliability prediction and its uses.
- To teach how to model tests under normal operating conditions and accelerated conditions.
- To teach analysis of data based on one-shot devices- units that are accompanied by an irreversible chemical reaction or physical destruction and can no longer function properly after use, for example, military weapons.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Learn life-data and degradation-data analytic techniques used in manufacturing industries, along with reliability prediction methods for estimating component and system lifetimes.
- Model and plan tests for lifetime and degradation datasets, including those conducted under accelerated environmental conditions.
- Analyze one-shot testing devices and interpret results for reliability assessment.

Syllabus of DSE - 4(j):

Unit I: Introduction **(10 hours)**
Product Life Cycle, Integrating reliability into product's life cycle, Reliability tasks for a typical product life cycle, Reliability Metrics, Product's Life distributions, Hard Failure and Soft Failure, Reliability Prediction: Introduction, Uses, FMEA, FTA, Role of Testing.

Unit II: **Non-Accelerated Tests** **(12 hours)**
Life data analysis with complete, time-censored and failure censored data sets, Degradation data, Relation of Degradation to Failure, Degradation Modelling: Data Driven Models; Models based on Stochastic Processes (Wiener and Gamma Processes).

Unit III: Accelerated Tests (ATs) **(14 hours)**
Need for Accelerated Tests, Types of Accelerated Tests: Accelerated Life Tests (ALTs) and Accelerated Degradation Tests (ADTs), Types of Stress Schemes-Constant-Stress; Step-Stress; Progressive Stress; Cyclic Stress; Random Stress; and their various combinations, Stress- Life Relationships, Acceleration Factor, Test Plans, constant-stress and step-stress ALT Plans, ALT under periodic inspection, ADT plans under constant-stress and step-stress loadings.

Unit IV: Analysis of One-shot Devices **(9 hours)**
One shot device testing data, one-shot devices with competing risks, Accelerated Testing using one-shot devices.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Balakrishnan, N., Ling, H.L., and So, H. Y. (2021). *Accelerated Life Testing of one-shot devices – Data Collection and Analysis*, Wiley.
2. Hφyland, A. and M. Rausand (2004). *System Reliability Theory: Models and Statistical Methods, 2nd edition* John Wiley & Sons Inc., Hobokens, New Jersey.
3. Nelson, W.B. (1990). *Accelerated Testing: Statistical Models, Test Plans, and Data Analysis*, John Wiley & Sons Inc., Hoboken, New Jersey.
4. Yang, G. (2007). *Life Cycle Reliability Engineering*, John Wiley & Sons, Inc., Hoboken, New Jersey.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(k): QUEUEING NETWORKS

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		
Queueing Networks (DSE - 4(k))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- Understand classifications of queueing networks, their probabilistic foundations, and derive product-form and non-product-form solutions for open and closed networks.
- Apply computational algorithms such as Convolution, Mean Value Analysis, and Norton's Theorem to evaluate network performance and analyze advanced models including multi-class, mixed, and blocking networks.
- Use queueing network theory to model and analyze real-life systems in computing, communication, manufacturing, and service domains.

Learning Outcomes:

Upon successful completion, students will be able to:
- Explain the fundamental principles and mathematical structure of queueing networks and derive/solve balance and traffic equations using key theorems (Jackson's and Gordon–Newell).
- Apply performance-evaluation algorithms including Mean Value Analysis (MVA) and Convolution, and analyze multi-class, blocking, and finite-capacity networks using exact and approximate methods.
- Model and interpret real-world systems across diverse domains using queueing-network frameworks and evaluate their performance effectively.

Syllabus of DSE - 4(k):

Unit I: Fundamentals of Queueing Networks (10 hours)
Introduction to queueing networks – nodes, routing mechanisms, classification (open, closed, mixed); Series (tandem) queues and cyclic queues; Queue output processes; Departure process from M/M/–/– queue; Time reversibility; Reversible Markov chains; Burke's Theorem; Product-form networks: motivation, global and local balance properties; Applications: Multi-stage service facilities, communication channels, manufacturing and healthcare systems.

Unit II: Open Queueing Networks (12 hours)
Structure and assumptions of open networks; Single-class networks; Traffic equations and stability conditions; Open networks of M/M/m type queues; Jackson's Theorem and product-form solutions; Extensions to Jackson's Theorem; Derivation of performance measures – mean queue length, waiting time, throughput, utilization. Applications: Computer and communication systems, call centers, logistics and routing systems.

Unit III: Closed Queueing Networks (12 hours)
Concept of closed networks and fixed customer populations; Gordon–Newell networks and theorem; Convolution algorithm for normalization constant; Mean Value Analysis (MVA) algorithm; Norton's Theorem for closed networks; Comparison of open vs closed networks; Derivation of throughput and response time measures. Applications: Computer job shops, repair/maintenance systems, closed-loop production and service systems.

Unit IV: Advanced Queueing Networks (11 hours)
Multi-class networks and BCMP networks; Mixed open and closed queueing networks; Models of blocking in open and closed networks of finite capacity queues; Approximate analytical methods for finite capacity networks (open and closed); Approximate analysis of open networks of GI/G/m queues using the Queueing Network Analyzer (QNA) approach. Applications: Performance modeling of service systems with limited resources, manufacturing lines with buffers, healthcare operations, and computer networks with congestion.

Tutorial component (if any) - Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Gross, D., Shortle, J. F., Thompson, J. M., & Harris, C. M. (2018). *Fundamentals of Queueing Theory* (5th Edition). Wiley.
2. Bose, S. K. (2002). *An Introduction to Queueing Systems* (1st Edition). Springer, New York.
3. Bolch, G., Greiner, S., de Meer, H., and Trivedi, K. S. (2006). *Queueing Networks and Markov Chains: Modeling and Performance Evaluation with Computer Science Applications* (2nd Edition). John Wiley & Sons, Inc., Hoboken, New Jersey.
4. Mitra, D. (1988). *Analysis of Queueing Networks*. MIT Press.
5. Balsamo, S., De Nitto Persone, V., and Onvural, R. (2001). *Analysis of Queueing Networks with Blocking*. Kluwer Academic Publishers.

Suggested Readings:

1. Medhi, J. (2003). *Stochastic Models in Queueing Theory* (2nd Edition). Academic Press.
2. Chen, H. & Yao, D. D. (2001). *Fundamentals of Queueing Networks: Performance, Asymptotics and Optimization*. Springer-Verlag.
3. Perron, H. G. (1994). *Queueing Networks with Blocking*. Oxford University Press.
4. Kobayashi, H. & Mark, B. L. (2008). *System Modeling and Analysis: Foundations of System Performance Evaluation*. Prentice Hall.
5. Buzacott, J. A. & Shanthikumar, J. G. (1993). *Stochastic Models of Manufacturing Systems*. Prentice Hall.

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

Skill Based Course – Semester IV

SBC – 4

Communicating Operational Research Models and Findings

SKILL BASED COURSE
SBC - 4: COMMUNICATING OPERATIONAL RESEARCH MODELS AND FINDINGS

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		
Communicating Operational Research Models and Findings (SBC - 4)	2	0	0	2	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:

- Train students to critically read and interpret OR literature.
- Develop skills for clear poster and oral communication of mathematical models.
- Enhance analytical reasoning, critical thinking, and teamwork.

Learning Outcomes:

Upon successful completion, students will be able to:

- Analyze OR papers and identify key modelling insights.
- Present OR models clearly using structured presentations and visual tools.
- Collaborate effectively to synthesize and communicate OR findings.

Practical component/task: **(60 hours)**

The following practical activities shall be carried out by the students:

1. Identify types of OR literature: theoretical, empirical, applied.
2. Read OR based research papers and extract OR model components.
3. Critically evaluate research methodology and conclusions.
4. Create graphical representations of OR models using proper structure and visuals.
5. Group analysis of assigned OR research paper(s).
6. Respond effectively to audience questions.
7. Prepare oral presentation on the research papers identified.
8. Conduct peer review to enhance communication quality.
9. Prepare a report on the identified research paper(s).

Essential Readings:

1. Selected papers from: *Operations Research and related journals*.
2. Rardin, Ronald (2017). *Optimization in Operations Research*. Pearson.

Suggested Readings:

1. Powell, Warren & Batt, Robert (2022). *Modeling for Insight*. Wiley.
2. Tufte, Edward (2001). *The Visual Display of Quantitative Information*. Graphics Press.

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

Generic Elective - Semester IV

GE - 4(a): Reliability and Maintenance Theory

GE - 4(b): Scheduling Techniques

GENERIC ELECTIVE
GE - 4(a): RELIABILITY AND MAINTENANCE 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		
Reliability and Maintenance Theory (GE - 4(a))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:

- To introduce the key concepts and methods in reliability engineering.
- To teach reliability modelling of systems with different configurations along with optimal reliability allocation and redundancy techniques.
- To teach concept of repair and its impact on the performance of the system along with formulation of maintenance and replacement policies.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Develop reliability models for non-repairable systems under various configurations and perform reliability assessment, including optimal system design through reliability and redundancy allocation.
- Model repairable systems using renewal processes, non-homogeneous Poisson processes, and state-space methods.
- Formulate appropriate system maintenance strategies to enhance overall system performance and reliability.

Syllabus of GE - 4(a):

Unit I: System Reliability **(9 hours)**
Basics of Reliability. Classes of life distributions based on Notions of Ageing. System Reliability: Reliability of Series, Parallel, Standby, k-out-of-n, Series-Parallel, Parallel -Series configurations and Bridge Structure. Multi-state System-Series and Parallel systems.

Unit II: Optimal Reliability Design Techniques **(10 hours)**
Optimal Reliability Allocation, Redundancy Allocation Problem: Formulation of optimal redundancy problem with a single restriction for a series system.

Unit III: Repairable System Modeling **(16 hours)**
Types of Repair, Availability theory: Types of Availability measures; Perfect Repair Models: Introduction to Renewal theory, Types of Renewal Processes and their Asymptotic Properties, Reward Renewal Processes Minimal Repair Models: Introduction to Non Homogenous Poisson Process, Power Law Model; State Space Methods: Markovian approach for reliability/ availability analysis of repairable series and parallel systems, systems with dependent components, and various types of standby systems, System Performance Characteristics, Load-Sharing Systems, Semi-Markovian Approach for one unit system reliability analysis.

Unit IV: Maintenance Policies **(10 hours)**
Corrective Maintenance; Preventive Maintenance, Age Replacement Policy: cost type criterion, Block Replacement Policy: Cost-type criterion. Preventive Maintenance: one-unit system with repair, Maintenance policies with minimal repairs.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Barlow, R. E., & Proschan, F. (1975). *Statistical theory of reliability and life testing*. Holt, Rinehert & Winston Inc.
2. Cox, D. R. (1967). *Renewal theory*. London: Methuen.
3. Gertsbakh, I. (2013). *Reliability theory with applications to preventive maintenance*. Springer.
4. Kapur, P. K., Kumar, S., & Garg, R. (1999). *Contributions to hardware and software reliability*. Singapore: World Scientific.
5. Kuo, W., & Zuo, M. J. (2003). *Optimal reliability modeling: principles and applications*. John Wiley & Sons.
6. Mitov, K. V., & Omey, E. (2014). *Renewal processes*. Springer. Nakagawa, T. (2005). Maintenance theory on reliability. London: Springer-Verlag.
7. Pham, H. (2003). *Handbook of reliability engineering*. London: Springer-Verlag. Rau, J. G. (1970). Optimization and probability in systems engineering. V.N. Reinhold Co.
8. Rausand, M., & Hoyland, A. (2003). *System reliability theory: models, statistical methods, and applications*. John Wiley & Sons.

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

GENERIC ELECTIVE
GE - 4(b): SCHEDULING TECHNIQUES

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Prerequisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Scheduling Techniques (GE - 4(b))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart a deep understanding of the theories and concepts underlying various scheduling problems in Operations Research.
- To develop knowledge of key areas such as network flow models, project management, and sequencing problems.
- To enhance the ability to apply scheduling and optimization techniques to real-world operational and managerial contexts.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and analyze mathematical models for network flow problems and project networks with deterministic and probabilistic activity durations and critically evaluate project schedules including cost–time trade-offs.
- Manage resources efficiently under operational and project constraints to improve overall system performance.
- Optimize job allocation in multi-machine production systems to minimize total elapsed time.

Syllabus of GE - 4(b):

Unit I: Network Scheduling: Fundamentals and Solution Methodology (10 hours)
Graphs and networks, Path, Cycle, Tree and Cut in a network, Node-arc incidence matrix, Excess capacity matrix, Flows in networks, Max flow- Min cut theorem, Flow augmenting path. Linear programming formulation of Maximal flow problem, Minimum cost flow problem, and Multi-commodity flow problem.

Unit II: Network Models and Applications (10 hours)
Shortest path problem, Travelling Salesman problem, Minimum spanning tree, Capacitated Network flow problem, Transhipment problem, Facility location models: Mathematical modelling and solution methodology.

Unit III: Project Scheduling **(15 hours)**
Project management with known and probabilistic activity times (CPM & PERT), constructing project networks: Gantt chart, Activity on arrow/Activity on node, Various types of floats and their significance, Project crashing, Linear programming formulation of Project crashing, Project updation, Resource constrained project scheduling: Resource levelling & Resource smoothing.

Unit IV: Theory of Sequencing **(10 hours)**
Flow-shop and Job-shop problems, Johnsons' optimality rule for a general Flow-shop problem, Parallel processing, General n/m Job-shop integer programming formulation.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Ahuja, R. K., Magnanti, T. L., Orlin, J. B., & Reddy, M. R. (1995). *Applications of network optimization. Handbooks in Operations Research and Management Science*. Elsevier.
2. Baker, K. R., & Trietsch, D. (2019). *Principles of sequencing and scheduling*. John Wiley & Sons Inc.
3. Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2010). *Linear programming and network flows*. John Wiley & Sons.
4. Elmaghraby, S. E. (1977). *Activity networks: Project planning and control by network models*. John Wiley & Sons Inc.
5. Ford, L. R., & Fulkerson, D. R. (2015). *Flows in networks*. Princeton University Press.
6. Jensen, P. A., & Barnes, J. W. (1980). *Network flow programming*. John Wiley & Sons Inc.
7. Wiest, J. D., & Levy, F. K. (1977). *Management guide to PERT/CPM: with GERT/PDM/DCPM and other networks*. Prentice-Hall of India Pvt. Ltd.

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SYLLABI OF SEMESTERS III & IV

(STRUCTURE - II)

Discipline Specific Core - Semester III

DSC - 7: Econometric Modeling and Forecasting

DSC - 8: Marketing Management

DISCIPLINE SPECIFIC CORE
DSC - 7: ECONOMETRIC MODELING AND 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		
Econometric Modeling and Forecasting (DSC - 7)	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- Introduce students to the principles, applications, and forecasting aspects of econometric modeling.
- Develop proficiency in multiple linear regression, logistic regression, time series analysis, and advanced econometric frameworks such as lag structures and simultaneous equation models.
- Enable students to apply econometric tools to real-world problems and accurately interpret empirical results.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Explain key concepts, assumptions, and challenges in econometric and time-series modeling, including models with quantitative and qualitative variables.
- Construct, interpret, and evaluate linear econometric and time-series models for forecasting and empirical analysis.
- Formulate and analyze advanced structures such as distributed-lag models and simultaneous-equation systems to address complex real-world applications.

Syllabus of DSC - 7:

Unit I: Introduction **(8 hours)**
Types of data: Time series data, Cross-sectional data, Panel data, Importance of forecasting, Classification of forecast methods, Conceptual framework of a forecast system, Forecasting criteria.

Unit II: Regression Models and Analysis **(14 hours)**
Classical linear regression models (CLRMs): Multiple linear regression, Multiple and partial correlation coefficients, Violating the assumptions of CLRMs: Multi-collinearity, Heteroscedasticity, Autocorrelation, Non-linear regression models, Multivariate logistic regression model.

Unit III: Time Series Modeling and Analysis **(14 hours)**
Components of time series, Time series decomposition models, Exponential smoothing methods, Stationary and non-stationary time series, Consequence of non-stationarity, Detection of non-stationarity, Autoregressive (AR) time series models, Moving average (MA) models, ARMA models, ARIMA models, Box-Jenkins approach to forecasting.

Unit IV: Lag Models and Simultaneous Equation Models **(9 hours)**
Distributed lag models using Koyck transformation and Almon transformation, Simultaneous equations models: Basic definitions, Identification problem, Estimation, Forecasting from a simultaneous model.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Brockwell, P. J., & Davis, R. A. (2002). *Introduction to time series and forecasting*. New York: Springer.
2. Dougherty, C. (2011). *Introduction to econometrics* (4th ed.). New York: Oxford University Press.
3. Johnston, J. (1984). *Econometric methods* (3rd ed.). New York: Mc-Graw Hill.
4. Koutsoyiannis, A. (2001). *Theory of econometrics* (2nd ed.). New York: Palgrave Macmillan.
5. Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (1998). *Forecasting: methods and applications* (3rd ed.). New York: John Wiley & Sons Inc.
6. Montgomery, D. C., Jennings, C. L., & Kulahci, M. (2008). *Introduction to time series analysis and forecasting*. New York: Wiley-Blackwell.
7. Montgomery, D. C., Peck, E. A., & Vining, G. G. (2012). *Introduction to linear regression analysis* (5th ed.). New York: John Wiley & Sons Inc.

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DISCIPLINE SPECIFIC CORE
DSC - 8: MARKETING 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		
Marketing Management (DSC - 8)	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart knowledge of introductory concepts and principles of Marketing.
- To make the students understand the theoretical basics of different market phenomena related to Customer Buying Behavior, Product and Brand Management, Pricing, Distribution and Promotional strategies.
- To impart the analytical thinking and nurture mathematical modeling concepts to solve real life management science problems.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Acquire analytical and decision-making skills applicable to business and management, including understanding marketing strategy formulation, implementation, and evaluation.
- Analyze market dynamics from producer and consumer perspectives to support strategic decision-making.
- Model innovation diffusion and apply quantitative techniques for sales forecasting of new products.

Syllabus of DSC - 8:

Unit I: Introduction to Marketing Management (8 hours)
Concept of Marketing and its role in Business and Public Organization, Role of Marketing Manager, Marketing Orientation**,** Marketing Mix-The traditional 4Ps, Modern components of the mix-the additional 3Ps, developing an effective marketing mix.

Unit II: Marketing Environment & Consumer Buying Behavior (11 hours)
Concept of perfect and imperfect competition, Factors influencing consumer buying behavior, External-Internal influence diffusion model for sales forecasting, Characteristics of a buyer, Difference between adopter and buyer, Adopter categorization.

Unit III: Marketing Mix-Product & Price (12 hours)
Product Life Cycle (PLC), Product line, Product mix strategies, New product development, Concept of multi-generations of products, Brand, Brand name selection, Brand equity, Brand switching analysis; Pricing: Elasticity Concept, marginal Analysis, Factors affecting pricing decision, Pricing methods, Optimal purchasing policies under fluctuating prices, Joint optimization of price, quality, and promotional effort.

Unit IV: Marketing Mix- Place and Promotion **(14 hours)**
Channels of distribution, Locating company's warehouses; Promotion Management: Promotional decisions in the presence of competition. Spatial Allocation of Promotional Effort, Media Allocation of Advertisement, Sales Response to Advertising in Presence of Competition.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Armstrong, G., Adam, S., Denize, S., & Kotler, P. (2018). *Principles of marketing* (7th ed.). Pearson Australia.
2. Kotler, P., Keller, K. L., Chernev, A., Sheth, J. N., & Shainesh, G. (2025). *Marketing management* (17th ed.). Pearson.
3. Curtis, T. (2008). *Marketing for engineers, scientists and technologists*. John Wiley & Sons.
4. Dowling, G. R. (2004). *The art and science of marketing: Marketing for marketing managers*. Oxford University Press.
5. Hooley, G. J., & Hussey, M. K. (1999). *Quantitative methods in marketing* (2nd ed.). International Thomson Business Press.

Suggested Readings:

1. Lilien, G. L., Kotler, P., & Moorthy, K. S. (2003). *Marketing models* (Eastern Economy ed.). Prentice-Hall of India.
2. Anand, A., Aggrawal, D., & Agarwal, M. (2019). *Market assessment with OR applications*. CRC press.

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

Discipline Specific Elective – Semester III

DSE - 3(a): Bayesian Forecasting

DSE - 3(b): Data Warehousing and Data Mining

DSE - 3(c): Dynamic Optimization

DSE - 3(d): Health Care Management

DSE - 3(e): Marketing Analytics

DSE - 3(f): Multicriteria Decision-Making Techniques

DSE - 3(g): Quantitative Social Media Analysis

DSE - 3(h): Revenue Management

DSE - 3(i) : Stochastic Modeling

DSE - 3(j) : Supply Chain Management

DSE - 3(k): Warranty Modeling and Analysis

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(a): BAYESIAN 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		
Bayesian Forecasting (DSE - 3(a))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To acquaint students with short-term Bayesian Forecasting methods which utilize data as well as subjective information.
- To teach students formulation of Dynamic Linear Models (DLMs), Noise Models-ARMA models in DLM form and Dynamic Generalized Linear Models (DGLMs) and forecasting.
- To teach applications of the methods taught using examples from industry and business fields

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Formulate DLM, Noise Models, and DGLMs model for forecasting using Bayesian approach.
- Know how to update models for forecasting.
- To perform diagnostics checks of how well the model to be used for forecasting fits the data.

Syllabus of DSE - 3(a):

Unit I: Introduction **(12 hours)**
Basics of Bayesian Statistics, MCMC (Markov Chain Monte Carlo) simulation; Time Series and its components; Dynamic Systems; Bayesian Approach to Forecasting.

Unit II: Dynamic Linear Model (DLM) **(12 hours)**
Model Form; Updating; Forward Intervention; Component Forms: Polynomial Trend Components, Seasonal Component Models, Harmonic Analysis, Regression Components; Superposition: Block Structured Models; Variance Learning; Forecast Monitoring; Error Analysis Applications.

Unit III: Noise Models **(12 hours)**
Basics of Time Series Models; ARMA models in DLM Form; Dynamic noise models as component DLMs; Non-linear learning problems; Applications.

Unit IV: Dynamic Generalized Linear Models **(9 hours)**
Introduction; Dynamic regression framework; DGLM updating; Step ahead forecasting and filtering; Linearization in the DGLM; Applications.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Broemeling, L.D. (2019). *Bayesian Analysis of Time Series*, CRC Press, Taylor and Francis Group, New York.
2. Pole, A. West, M., and Harrison, J. (1994). *Applied Bayesian Forecasting and Time Series Analysis*, Springer Science+ Business Media, B.V.
3. West, M. and Harrison, J. (1989). *Bayesian Forecasting and Dynamic Models*, Springer Science+ Business Media, New York.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(b): DATA WAREHOUSING AND DATA MINING

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		
Data Warehousing and Data Mining (DSE - 3(b))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To provide a comprehensive understanding of data warehousing concepts and data mining techniques for knowledge discovery.
- To emphasize on data preprocessing, modeling, and analysis of large datasets.
- To develop the ability to design and implement models that support effective data-driven decision-making.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Explain core concepts, architectures, and processes of data warehousing and data mining, including data preprocessing, cleaning, and transformation.
- Implement association, classification, prediction, and clustering algorithms on real-world datasets and evaluate the discovered patterns for effective decision-making.
- Design and develop complete data warehousing and data-mining solutions tailored to specific business or research applications.

Syllabus of DSE - 3(b):

Unit I: Introduction to Data Warehousing: **(10 hours)**
Introduction to Decision Support System, Data Warehousing and Online Analytical Processing, Data Warehouse: Basic Concepts, Data Extraction, Cleanup, and Transformation Tools, Data Warehouse Modeling: Data Cube, Schema and OLAP, Data Warehouse Design and Usage, Data Warehouse Implementation.

Unit II: Fundamentals of Data Mining: **(11 hours)**
Introduction to Data Mining, Knowledge Discovery in Databases (KDD), Data Mining Functionalities, Application and Issues in Data Mining. Data Exploration: Types of Attributes; Statistical Description of Data; Data Visualization; Measuring similarity and dissimilarity. Data Preprocessing, Data Cleaning, Data Integration and Transformation, Data Discretization, Normalization. Association Rule Mining: Market Basket Analysis, Frequent Item sets, Closed Item sets, and Association Rules; Efficient and Scalable Frequent Item-sets Mining Methods: The Apriori algorithm, Improving the Efficiency of Apriori algorithm, Mining Frequent item sets using vertical data formats; Mining closed and maximal patterns.

Unit III: Foundations of Classification and Prediction **(12 hours)**
Introduction to classification and prediction; issues regarding Classification and Prediction, interpretability, and scalability and data preparation. Decision tree induction, Bayesian classification (Naïve Bayes), Rule-based classification, k-Nearest Neighbor (KNN), Introduction to Regression Techniques for Prediction, Model evaluation and selection.

Unit IV: Essentials of Cluster Analysis **(12 hours)**
Introduction to cluster analysis; types of data and distance measures; partitioning methods (K-Means, K-Medians, K-Medoids); Hierarchical clustering (Agglomerative, Divisive, Linkage criteria); Clustering high-dimensional data, Cluster validation.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Adriaans, P., & Zantinge, D. (1996). *Data mining*. Addison-Wesley.
2. Berry, M. J. A., & Linoff, G. (2011). *Data mining techniques: For marketing, sales, and customer relationship management* (3rd ed.). John Wiley & Sons.
3. Berson, A., & Smith, S. J. (2007). *Data warehousing, data mining, and OLAP* (10th reprint). McGraw-Hill.
4. Gupta, G. K. (2014). *Introduction to data mining with case studies* (3rd ed.). PHI Learning.
5. Han, J., Kamber, M., & Pei, J. (2011). *Data mining: Concepts and techniques* (3rd ed.). Morgan Kaufmann.
6. Larose, D. T., & Larose, C. D. (2015). *Data mining and predictive analytics* (2nd ed.). Wiley-Blackwell.

Suggested Readings:

1. Fayyad, U. M., Piatetsky-Shapiro, G., Smyth, P., & Uthurusamy, R. (Eds.). (1996). *Advances in knowledge discovery and data mining*. MIT Press.
2. Tan, P.-N., Steinbach, M., Karpatne, A., & Kumar, V. (2018). *Introduction to data mining* (2nd ed.). Pearson.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(c): DYNAMIC 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		
Dynamic Optimization (DSE - 3(c))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To introduce the principle of optimality and multi-stage decision-making using discrete and continuous optimization problems.
- To formulate and solve dynamic programming and optimal control problems with applications across various domains.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Understand and explain the principle of optimality and foundational concepts of multi-stage decision-making, including discrete dynamic programming and the calculus of variations with necessary and sufficient conditions for extrema.
- Formulate and solve additive/multiplicative separable-return discrete models, continuous-time and discrete-time optimal control problems, and systems governed by maximum-principle-based optimality conditions.
- Apply dynamic programming, calculus of variations, and optimal control frameworks to real-world decision-making scenarios.

Syllabus of DSE - 3(c):

Unit I: Discrete Dynamic Programming (16 hours)
Principle of optimality and multi-stage decision processes, Bellman's equation and recursive formulation of dynamic optimization problems, Optimal policies for models with additive and multiplicative separable returns in objective and constraint functions, Sequential and non-sequential discrete optimization models, Dimensionality reduction technique, Applications in real-world problems across diverse application domains.

Unit II: Calculus of Variations (8 hours)
Introduction to calculus of variations, Formulation of variational problems, Classification of functionals and their stationary values, Euler-Lagrange equation and its applications to variational problems.

Unit III: Methods for Variational Problems **(8 hours)**
Weak and strong extrema, Necessary and sufficient conditions for optimality, Constrained variational problems, Lagrange multiplier method.

Unit IV: Optimal Control Theory **(13 hours)**
Fundamentals of optimal control theory, Mathematical models of continuous-time and discrete-time control systems, Pontryagin's maximum principle and necessary conditions for optimality, Transversality conditions, Applications of optimal control methods in marketing, inventory systems, production planning, and financial investment.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Chiang, A. C. (1999). *Elements of Dynamic Optimization*. Waveland Press Inc.
2. Sethi, S. P., & Thompson, G. L. (2005). *Optimal Control Theory-Applications to Management Science and Economics* (2nd Edition). Springer.
3. Seierstad, A., & Sydsaeter, K. (1987). *Optimal Control Theory with Economic Applications*. Elsevier.
4. Hillier, F. S., & Lieberman, G. J. (2025). *Introduction to Operations Research- Concepts and Cases* (12th Edition). Tata McGraw Hill (Indian print).

Suggested Readings:

1. Kaufmann, A., & Cruon, R. (1967). *Dynamic Programming*. Academic Press.
2. Kirk, D. (2004). *Optimal Control Theory- An Introduction*. Dover Publication.
3. MacCluer, C. R. (2005). *Calculus of Variations-Mechanics, Control Theory, and Other Applications*. Prentice Hall.
4. Taha, H. A. (2022). *Operations Research- An Introduction* (11th Edition). 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.

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(d): HEALTH CARE 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		
Health Care Management (DSE - 3(d))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To analyze healthcare systems and operational processes using quantitative methods and operations research tools.
- To model and solve real-world healthcare operations problems with a focus on improving efficiency, resource utilization, and decision-making quality.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Apply quantitative and optimization-based methods to formulate, analyze, and solve operational challenges within healthcare systems, considering real-world constraints and complexities.
- Use analytical and data-driven tools to design, test, and evaluate process-improvement across key healthcare functions such as patient flow, resource utilization, staffing, capacity planning, and supply chain management.
- Interpret and assess model outputs to understand the impact of operational decisions on service quality, system performance, and overall healthcare delivery effectiveness, including applications in emergency service planning.

Syllabus of DSE - 3(d):

Unit I: Health Care Systems and Services Management (13 hours)
Overview of global health and health care systems, Challenges in health care delivery across diverse populations, Effectiveness, efficiency, and value-based care, Decision-making frameworks in clinical and administrative settings, Distinctive characteristics of health care services and their operational implications, Principles and practices of health care services management.

Unit II: Forecasting in Health Care Operations (8 hours)
Health care demand forecasting, Capacity and resource planning, Forecast information for operational and strategic decision-making in health care services, Decision-making frameworks for service delivery, access, and system responsiveness improvements.

Unit III: Facility Planning in Health Care Operations (9 hours)
Location planning methods and their application to health care facility placement and accessibility, Location-allocation optimization models in health service: the p-median problem, location set covering problem, and maximal covering location problem, Facility layout design for enhancing workflow efficiency and patient care productivity, Analysis of basic layout design problems in clinical and support service environments.

Unit IV: Resource and Operations Optimization in Health Care (15 hours)
Workload management approaches for clinical, diagnostics and support services, Staffing and scheduling strategies to manage patient demand, and service coverage, Productivity assessment and performance indicators in health care operations, Optimization models for resource allocation and capacity planning, Principles of inventory management for pharmaceuticals, consumables, and medical supplies, Queuing theory applications for patient-flow, waiting time and service-time analysis, Introduction to simulation modeling for evaluating operational alternatives and improving health care service delivery.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Anupindi, R., Chopra, S., Deshmukh, S., Van Mieghem, J., & Zemel, E. (2012). *Managing Business Process Flows* (3rd Edition). Prentice Hall.
2. Brandeau, M. L., Sainfort, F., & Pierskalla, W. P. (2005). *Operations Research and Health Care: A Handbook of Methods and Applications*. Springer.
3. Denton, B.T. (2013). *Handbook of Healthcare Operations Management: Methods and Applications*. Springer.
4. Ozcan, Y. A. (2017). *Quantitative Methods in Health Care Management: Techniques and Applications*. John Wiley & Sons.
5. Rahman, S. U., & Smith, D. K. (2000). Use of location-allocation models in health service development planning in developing nations. *European Journal of Operational Research, 123(3), 437-452.* Elsevier.
6. Research articles in journals and reports from the Census of India, WHO, NSSO, UNICEF, etc.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(e): MARKETING ANALYTICS

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		
Marketing Analytics (DSE - 3(e))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To provide conceptual understanding of marketing analytics and its strategic role in decision making.
- To develop the ability to analyze customer data for segmentation, targeting, and loyalty modeling.
- To apply predictive and prescriptive models for customer valuation, product bundling, and advertising decisions.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Understand the concepts, scope, and applications of marketing analytics and apply analytical models for customer segmentation, targeting, and loyalty analysis.
- Evaluate customer preferences, value, and product-bundling opportunities using quantitative and data-driven tools.
- Utilize analytical insights to enhance marketing performance, optimize decisions, and improve customer engagement.

Syllabus of DSE - 3(e):

Unit I: Foundations of Marketing Analytics (8 hours)
Conceptual introduction to marketing analytics, Evolution, scope, and significance of analytics in marketing, Data for marketing analytics: sources, types, and data quality, Problem-solving and decision-making models in marketing.

Unit II: Customer Segmentation and Targeting (12 hours)
Prospecting and targeting the right customers, Market segmentation using analytical models: Logistic Regression, Neural Networks, Decision Trees, Predicting customer response through RFM analysis, Introduction to customer loyalty: 3Rs of loyalty, Modeling loyalty using Confirmatory Factor Analysis (CFA), Structural Equation Modeling (SEM), and Partial Least Squares (PLS).

Unit III: Understanding Customer Preferences and Value (10 hours)
Choice modeling and customer preference estimation, Concept and benefits of product bundling, Market Basket Analysis and association rules, Customer Lifetime Value (CLV) estimation, Allocating marketing resources between acquisition and retention strategies.

Unit IV: Digital and Network-Based Marketing Analytics (15 hours)
Online advertising analytics: display ads, search ads (PPC), and media selection models, Next-product-to-buy and recommendation systems, Learning from customer purchases and ratings, Cross-selling and up-selling strategies, Social network analytics: network structure, random and regular networks, diffusion over networks, Text analytics, online user content analysis, and mobile commerce insights.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Winston W.L. (2020). *Marketing analytics: Data-driven techniques with Microsoft Excel*. John Wiley & Sons, New Jersey.
2. Sorger S. (2013). *Marketing Analytics: Strategic Models and Metrics*. Admiral Press.
3. Hemann, C. and K. Burbary (2018). *Digital marketing analytics: Making sense of consumer data in a digital world*, Pearson Education.
4. Mike Grigsby (2016). *Advanced Customer Analytics-Targeting, Valuing, Segmenting and Loyalty Techniques*, Kogan pages.

Suggested Readings:

1. Wedel, M., & Kamakura, W. A. (2012). *Market Segmentation: Conceptual and Methodological Foundations*. Springer.
2. Tandon, A., & Aggarwal, A. G. (2023). *Consumer behaviour in digital markets*, Macmillan.
3. Shmueli, G., Bruce, P. C., Patel, N. R., & Yahav, I. (2017). *Data Mining for Business Analytics: Concepts, Techniques, and Applications in R*. Wiley.
4. Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate Data Analysis*. Pearson Education.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(f): MULTICRITERIA DECISION-MAKING TECHNIQUES

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		
Multicriteria Decision-Making Techniques (DSE - 3(f))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To develop a strong conceptual and mathematical foundation in Multicriteria Decision-Making (MCDM) models and methodologies.
- To equip students with the ability to formulate, model, and analyze complex decision-making problems involving multiple conflicting criteria and alternatives.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Formulate and structure complex decision problems involving multiple conflicting criteria, and operational constraints across diverse application domains.
- Apply appropriate MCDM and performance evaluation techniques, including efficiency assessment models to analyze and compare decision alternatives or decision-making units (DMUs).
- Utilize MCDM frameworks to generate evidence-based insights that support informed policy, engineering, and management decisions.

Syllabus of DSE - 3(f):

Unit I: Multi-Objective Optimization **(10 hours)**
Concept of trade-offs and conflicting objectives, Pareto optimality, Proper pareto optimality, Lexicographic optimality, Optimality conditions, Weighted sum method, ε-Constraint method.

Unit II: **Performance and Priority Evaluation Techniques** **(13 hours)**
Data envelopment analysis: input and output-oriented formulations, efficient and inefficient DMUs, slack analysis and performance targets for inefficient DMUs, graphical analysis for efficient frontier, Charnes, Cooper and Rhodes model for constant returns to scale, Banker, Charnes and Cooper model for variable returns to scale, Analytic hierarchy process: construction of pairwise comparison matrices, ranking and weighting information using eigen vector method and approximation methods, extension to group decision-making.

Unit III: Attribute Utility Models **(10 hours)**
Utility and scoring models: construction of single-attribute and multi-attribute utility functions, additive and multiplicative utility formulations, scaling and normalization of criteria, weighted linear and multiplicative scoring models, Ranking and evaluating alternatives: Simple additive weighting method, Weighted product method, Multi-attribute utility method.

Unit IV: Compensatory Models **(12 hours)**
Distance-based and compromise ranking methods, Principle of compromise solutions, Positive and negative ideal solutions, TOPSIS method: normalization, weight assignment, ideal and anti-ideal determination, separation measures, relative closeness coefficient, VIKOR method: utility and regret measures, ranking index, decision strategy for compromise solutions.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Triantaphyllou, E. (2000). *Multi-Criteria Decision-Making Methods: A Comparative Study*. Springer.
2. Ramanathan, R. (2003). *Introduction to Data Envelopment Analysis: A Tool for Performance Measurement.* Sage Publications Pvt Ltd.
3. Brunelli, M. (2015). *Introduction to the Analytic Hierarchy Process.* Springer.
4. Steuer, R. E. (1986). *Multiple Criteria Optimization-Theory, Computation, and Application.* Wiley Series in Probability and Mathematical Statistics-Applied, Wiley.
5. Tzeng, G. H., & Huang, J. J. (2011). *Multiple Attribute Decision Making: Methods and Applications.* CRC Press.
6. Research articles in journals from SCI/SCIE/SCOPUS Indexed Journals.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(g): QUANTITATIVE SOCIAL MEDIA 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		
Quantitative Social Media Analysis (DSE - 3(g))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To introduce the basic concepts of Social Media Analysis,
- To teach the important characteristics of various social media
- To teach the students about mathematical models for information diffusion

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Understand the principles of marketing with a focus on social media marketing, including measurement of content characteristics.
- Explain foundational concepts of social media analysis using social network theory.
- Mathematically model information diffusion and epidemic dynamics and understand mechanisms of viral marketing.

Syllabus of DSE - 3(g):

Unit I: Introduction to Social Media (10 hours)
Fundamental concepts of the Social Media Research Domain and related Areas, Content Characteristics, Content Dynamics, and User Dynamics, Introduction to Network Concepts and Random Network Models

Unit II: Social Media Analytics (13 hours)
Fundamentals of Social Media Analytics-Network Building and Visualization techniques, Introduction to Community Detection and Link Prediction methods, Social Media Monitoring, Social Media Advertising Analytics

Unit III: Information Diffusion (10 hours)
Quantification of the virality of information in online Social Networks, Probabilistic Models of Information Flow, Cascading Behavior, and epidemic modeling to understand the spread of information, Understanding Over the top (OTT) platforms and Freemium as an advertising strategy for OTT platforms

Unit IV: YouTube: An Effective Social Media (12 hours)
View count model for viewership classification & prediction, and further classification of viewers based on the time of their activation. Modeling the growing YouTube Viewership and fitting these dynamic models to various extracted datasets for the viewership growth Pattern, dynamic internet market size-based modeling for YouTube videos

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Chakraborty, T. (2021). *Social network analysis*. Wiley.
2. Zafarani, R., Abbasi, M. A., & Liu, H. (2017). *Social media mining: An introduction*. Cambridge University Press.
3. Barabási, A.-L**.** (2017). *Network science*. Cambridge University Press.
4. HYang, S., Keller, F. B., & Zheng, L. (2016). *Social network analysis: Methods and examples*. SAGE Publications, Inc.
5. Research articles from journals of national and international repute.

Suggested Readings:

1. Borgatti, S. P., Everett, M. G., Johnson, J. C., & Agneessens, F. (2022). *Analyzing social networks using R*. SAGE Publications.
2. Aggrawal, N., & Anand, A**.** (2022). *Social networks: Modelling and analysis*. CRC Press.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(h): REVENUE 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		
Revenue Management DSE - 3(h)	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To examine the fundamental principles of pricing and the concept of revenue management as an emerging paradigm in managerial practices across various industries.
- To analyse capacity allocation and price-based revenue management models, along with the optimization techniques employed in revenue management.
- To evaluate the application of revenue management across different industry sectors and identify the key factors influencing its successful implementation.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Formulate and revise pricing and product availability decisions across multiple selling channels to maximize a firm's profitability.
- Develop, analyse, and solve revenue optimization models and apply them effectively within organizational settings.
- Identify and leverage opportunities for revenue optimization across diverse business environments.

Syllabus of DSE - 3(h):

Unit I: Introduction to Pricing and Revenue Management (6 hours)
History of Pricing and Revenue Optimization. Strategies of Price optimization. Conceptual framework of Revenue Management. Booking controls. Revenue management system. Factors affecting revenue management. Role of revenue management in various industries.

Unit II: Price Optimization (15 hours)
Basic Price Optimization: The Price-Response Function, measure of Price sensitivity, Price Response with Competition. Price Differentiation: The Economics and Tactics of Price Differentiation, Calculating Differentiated Prices, Price Differentiation and Consumer Welfare. Optimal Pricing with Supply Constraint, Market Segmentation and Supply Constraints, Variable Pricing.

Unit III: Capacity Allocation in RM (15 hours)
Capacity Allocation Models: Littlewood's two class model, capacity allocation for multiple classes (n-class model), expected marginal seat revenue models (EMSR-a and EMSR-b). Capacity allocation for multiple resources: Network Revenue Management and its applicability. Network RM via Linear Programming approach. Overbooking models: overbooking based on service criteria, economic criteria (simple risk-based booking limit model). Overbooking problem with multiple products/classes and multiple resources.

Unit IV: Price based RM and Applications (9 hours)
Applicability of dynamic pricing. Markdown pricing. Promotion based pricing. Customized pricing. Implementing RM in various industries - hotels, car rentals, manufacturing, retailing, sports centre, online travel portals, restaurants, freight, railways. Factors critical in making a RM system effective

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Cross, G. R. (1997). *Revenue management: Hard-core tactics for market domination*: by Robert G. Cross. Broadway Books, 1540 Broadway, New York, NY 10036, 1997.
2. Lilien, G. L., Kotler, P., & Moorthy, K. S. (1995). *Marketing models*. Prentice Hall.
3. Nagle, T. T., & Müller, G. (2017). *The strategy and tactics of pricing: A guide to growing more profitably*. Routledge.
4. Phillips, R. L. (2005). *Pricing and revenue optimization*. Stanford University Press.
5. Sfodera, F. (Ed.). (2006). *The spread of yield management practices: the need for systematic approaches*. Springer Science & Business Media.
6. Talluri, K. T., & Van Ryzin, G. J. (2006). *The theory and practice of revenue management* (Vol. 68). Springer Science & Business Media.
7. Yeoman, I., & McMahon-Beattie, U. (Eds.). (2004). *Revenue management and pricing: Case studies and applications*. Cengage Learning EMEA.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(i): STOCHASTIC MODELING

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		
Stochastic Modeling (DSE - 3(i))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:

- Understand the principles, structure, and classification of stochastic processes and their role in modeling dynamic systems, with emphasis on discrete- and continuous-time models such as Markov and Poisson processes.
- Construct and evaluate stochastic models including random walks, martingales, diffusion-type processes, and Brownian motion for applications in finance, engineering, and related fields.
- Extend basic Markov models to semi-Markov and renewal processes and analyze their relevance in operational and real-world systems.

Learning Outcomes:

Upon successful completion, students will be able to:

- Classify stochastic processes by time parameter, state space, and dependence structure, and formulate DTMC and CTMC models to derive transient and steady-state distributions.
- Apply and simulate random walk, martingale, semi-Markov, and renewal models to evaluate probabilistic behavior, reliability, and operational efficiency.
- Develop and implement diffusion-based models, including Brownian motion and geometric Brownian motion, for dynamic and financial forecasting.

Syllabus of DSE - 3(i):

Unit I: Introduction to Stochastic Processes (6 hours)

Definition of stochastic process; Classification into discrete and continuous time; Concept of state space, index set, and sample paths; Stationary and non-stationary processes; Basic ideas of probabilistic evolution and dependence; Markov property and memoryless processes; Examples of stochastic processes in operational research, finance, and engineering.

Unit II: Discrete-Time Stochastic Models (13 hours)

Discrete-Time Markov Chains (DTMC) – definition, transition probability matrix, Chapman–Kolmogorov equations, classification of states (transient, recurrent, periodic, absorbing), limiting and stationary distributions, ergodic chains, mean recurrence times; Random walks — simple, symmetric and asymmetric, boundary crossing problems, gambler's ruin problem and applications; Martingales – definition, properties, examples, and applications in fair game and financial modeling.

Unit III: Continuous-Time Stochastic Models (13 hours)
Poisson Process – definition, event occurrence times, superposition and splitting mechanisms, compound Poisson process; Continuous-Time Markov Chains (CTMC) – transition rate matrix, Kolmogorov forward and backward equations, birth-death processes, transient analysis and limiting behavior; Renewal process – basic definition, concept and simple applications.

Unit IV: Advanced Stochastic Models (13 hours)
Semi-Markov processes – definition, transition probability functions, limiting behavior, relation to Markov and renewal processes, applications in system performance analysis; Martingales – revisited with continuous-time perspective; Brownian motion – definition, properties, continuity, first passage times; Geometric Brownian Motion (GBM) – definition, stochastic differential form, properties, and applications in finance and dynamic system modeling.

Tutorial component (if any) - Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Blanco, L., Arunachalam, V., & Dharmaraja, S. (2016). *Introduction to Probability and Stochastic Processes with Applications.* Wiley (Asian Edition).
2. Çinlar, E. (2013). *Introduction to Stochastic Processes.* Dover Publications. Karlin, S., & Taylor, H. M. (1975). *A First Course in Stochastic Processes.* Academic Press.
3. Kulkarni, V. G. (2016). *Modeling and Analysis of Stochastic Systems* (3rd Edition). CRC Press (Taylor & Francis Group).
4. Medhi, J. (2009). *Stochastic Processes* (3rd Edition). New Age International Publishers.
5. Ross, S. M. (1995). *Stochastic Processes* (2nd Edition). John Wiley & Sons.
6. Taylor, H. M., & Karlin, S. (2010). *An Introduction to Stochastic Modeling* (4th Edition). Academic Press (Elsevier).

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(j): SUPPLY CHAIN 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		
Supply Chain Management (DSE - 3(j))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- Impart the knowledge of concepts related to supply chain management with emphasis on informed decision-making in real world supply chain decisions.
- Analyze and formulate mathematical and analytical models to optimize supply chain networks, facility locations, and distribution strategies.
- Analyze and model sustainable, resilient, and global supply chain networks.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Define key supply chain terminologies and explain how strategic, tactical, and operational decisions influence overall performance.
- Use performance indicators, supply chain drivers, and quantitative analysis to support decision-making, identify inefficiencies, and assess supplier selection and allocation strategies through multi-criteria frameworks.
- Design resilient and optimized supply chain networks that integrate risk management, sustainability practices, and environmental considerations.

Syllabus of DSE - 3(j):

Unit I: Fundamentals of Supply Chain Management (10 hours)
Introduction to Supply Chain Management- Scope & Objectives; Evolution, Components of the Supply Chain and Supply-chain as flows, Supply Chain as a Decision System: Importance of Supply Chain Decisions, Decision Phases; Supply Chain vs. Logistics; Supply Chain Strategy and Performance, Supply Chain Drivers and Metrics, Assessing and Managing Supply Chain Performance, Role of Optimization in Supply Chain Planning, Introduction to Supply Chain Analytics: descriptive, predictive, prescriptive frameworks.

Unit II: Network Design, Facility Location and Distribution Decisions (12 hours)
Introduction to Supply Chain Network Design. Factors Influencing Network Configuration; Inbound and Outbound Logistics ,roles, flows and integration with network design, Distribution Network Types and Design Options, Framework for Network Design Decisions and Mathematical Modeling, Supply Chain Network Optimization: Facility Location Fundamentals, Warehouse Location, Distribution

Planning, Location-Distribution with Dedicated Warehouses Continuous Location Models, The capacitated plant location Network Optimization Model: With single sourcing, with simultaneous plants and warehouses location and distribution decisions.

Unit III: Supply Chain Planning, Coordination, and Supplier Selection (12 hours)

Role of Demand Forecasting in Supply Chain Management, Alternatives for Managing Demand and Supply, Tabular and Optimization Models for Aggregate Planning with Linear and Non-Linear Programming, Ratchet Effect; Bullwhip Effect, Coordination in Supply chain, Supplier selection problem: stages, criteria, and strategies. Multi-criteria supplier evaluation methods, Mathematical models for supplier allocation, Multi-Objective Supplier Allocation Model.

Unit IV: Sustainable, Resilient, and Global Supply Chain Optimization (11 hours)

Global supply chain, Reverse supply chain, closed loop supply chain, green supply chain, Sustainability in supply chain, Lean Manufacturing and Agile supply chain, Risk in Supply Chain, Ripple Effect, Disruption in Supply Chain, Managing and Modeling Supply Chain Resilience.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Ravindran, A. R., Warsing, D. P., Jr., & Griffin, P. M. (2023). *Supply chain engineering: Models and applications* (2nd edition). CRC Press
2. Chopra, S., & Meindl, P. (2020). *Supply chain management: Strategy, planning & operation* (7th edition). Pearson.
3. Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., & Shankar, R. (2019). *Designing and managing the supply chain: Concepts, strategies, and case studies* (4th edition). McGraw Hill Education (India).
4. Ivanov, D. (2021). *Introduction to supply chain resilience: Management, modelling, technology*. Springer Nature.

Suggested Readings:

1. Christopher, M. (2023). *Logistics & supply chain management* (6th edition). Pearson Education.
2. Shapiro, J. F. (2006). *Modeling the supply chain* (2nd edition). Duxbury Press.
3. Gupta, S. M. (Ed.). (2013). *Reverse supply chains: Issues and analysis*. CRC Press.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 3(k): WARRANTY MODELING AND 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		
Warranty Modeling and Analysis (DSE - 3(k))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:

- To explain warranty as a critical element in the marketing of products – a concept that is important to both the seller and the buyer of virtually any consumer or commercial product.
- To teach methodology behind formulation of one-dimensional, two-dimensional and extended warranties.
- To teach how to analyze warranty data.

Learning Outcomes:

Upon successful completion of this course, students will be able to:

- Formulate warranty policies.
- Deal with cost and optimization problems from the manufacturers' and buyers' point of view.
- Analyze warranty data.

Syllabus of DSE - 3(k):

Unit I: Introduction **(12 hours)**
Products: Product Classification, Product Performance, Product Warranty, Product Reliability; Classification of Warranties: One-Dimensional (1-D) Warranties, Two-Dimensional (2-D) Warranties, Group Warranties, Reliability Improvement Warranties, Extended Warranties; Warranty Data Collection: Types & Sources of Data, Warranty Claims Data.

Unit II: **Models & Techniques** **(12 hours)**
Cost Models for 1-D Warranties- Per Unit Cost: FRW Policy, Renewing FRW Policy, Non-Renewing PRW Policy, Life Cycle Cost Analysis per unit sale: Non-renewing FRW Policy, Non-Renewing PRW Policy. Cost Models for 2-D Warranties – Modeling Failures & Claims (Type-I usage), Warranty Cost Analysis unit – Different Approaches.

Unit III: Extended Warranties (12 hours)

System Degradation & Maintenance, Modelling & Analysis of Degradation and Maintenance (1-D Formulations), Extended & Maintenance Service Contracts Cost Analysis – Cost Analysis of Base Warranty, Cost Analysis of Extended Warranty, Cost Analysis of Maintenance Service Contracts, Basics of Lease Contracts.

Unit IV: Warranty Data Analysis and management (9 hours)

Analysis of 1-D data using competing risk models, Acceleration Failure Time Models, Proportional Hazard (P-H) models, Regression Models; Analysis of 2-D data – based on usage rate, composite scale, bivariate model formulation, forecasting expected warranty claim; use of warranty data for improving current products and operations, role of warranty data in new product development.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Blischke, W. R, Karim. M. R. and Murthy, D.N.P (2001). *Warranty Data Collection and Analysis*, Springer-Verlag London Ltd.
2. Blischke W. R. and Murthy, D.N.P. (1994). *Warranty cost analysis*. New York: Marcel Dekker.
3. Murthy, D.N.P. and Jack, N. (2014). *Extended Warranties, Maintenance Service, and Lease Contract: Modeling and Analysis for Decision Making*, Springer
4. Thomas, M. U. (2006). *Reliability and Warranties: Methods for Product Development and Quality Improvement*, CRC Taylor and Francis Group, New York.
5. Yang, G. (2007). *Life Cycle Reliability Engineering*, John Wiley & Sons, Inc., Hoboken, New Jersey.

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

Generic Elective - Semester III

GE - 3(a): Marketing Management

GE - 3(b): Health Care Management

GE - 3(c): Revenue Management

GE - 3(d): Warranty Modeling and Analysis

GENERIC ELECTIVE
GE - 3(a): MARKETING 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		
Marketing Management (GE - 3(a))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart knowledge of introductory concepts and principles of Marketing.
- To make the students understand the theoretical basics of different market phenomena related to Customer Buying Behavior, Product and Brand Management, Pricing, Distribution and Promotional strategies.
- To impart the analytical thinking and nurture mathematical modeling concepts to solve real life management science problems.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Acquire analytical and decision-making skills applicable to business and management, including understanding marketing strategy formulation, implementation, and evaluation.
- Analyze market dynamics from producer and consumer perspectives to support strategic decision-making.
- Model innovation diffusion and apply quantitative techniques for sales forecasting of new products

Syllabus of GE - 3(a):

Unit I: Introduction to Marketing Management (8 hours)
Concept of Marketing and its role in Business and Public Organization, Role of Marketing Manager, Marketing Orientation, Marketing Mix-The traditional 4Ps, Modern components of the mix-the additional 3Ps, developing an effective marketing mix.

Unit II: Marketing Environment & Consumer Buying Behavior (11 hours)
Concept of perfect and imperfect competition, Factors influencing consumer buying behavior, External-Internal influence diffusion model for sales forecasting, Characteristics of a buyer, Difference between adopter and buyer, Adopter categorization.

Unit III: Marketing Mix-Product & Price (12 hours)
Product Life Cycle (PLC), Product line, Product mix strategies, New product development, Concept of multi-generations of products, Brand, Brand name selection, Brand equity, Brand switching analysis; Pricing: Elasticity Concept, marginal Analysis, Factors affecting pricing decision, Pricing methods, Optimal purchasing policies under fluctuating prices, Joint optimization of price, quality, and promotional effort.

Unit IV: Marketing Mix- Place and Promotion **(14 hours)**
Channels of distribution, Locating company's warehouses; Promotion Management: Promotional decisions in the presence of competition. Spatial Allocation of Promotional Effort, Media Allocation of Advertisement, Sales Response to Advertising in Presence of Competition.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Armstrong, G., Adam, S., Denize, S., & Kotler, P. (2018). *Principles of marketing* (7th ed.). Pearson Australia.
2. Kotler, P., Keller, K. L., Chernev, A., Sheth, J. N., & Shainesh, G. (2025). *Marketing management* (17th ed.). Pearson.
3. Curtis, T. (2008). *Marketing for engineers, scientists and technologists*. John Wiley & Sons.
4. Dowling, G. R. (2004). *The art and science of marketing: Marketing for marketing managers*. Oxford University Press.
5. Hooley, G. J., & Hussey, M. K. (1999). *Quantitative methods in marketing* (2nd ed.). International Thomson Business Press.

Suggested Readings:

1. Lilien, G. L., Kotler, P., & Moorthy, K. S. (2003). *Marketing models* (Eastern Economy ed.). Prentice-Hall of India.
2. Anand, A., Aggrawal, D., & Agarwal, M. (2019). *Market assessment with OR applications*. CRC press.

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

GENERIC ELECTIVE
GE - 3(b): HEALTH CARE 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		
Health Care Management (GE - 3(b))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To analyze healthcare systems and operational processes using quantitative methods and operations research tools.
- To model and solve real-world healthcare operations problems with a focus on improving efficiency, resource utilization, and decision-making quality.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Apply quantitative and optimization-based methods to formulate, analyze, and solve operational challenges within healthcare systems, considering real-world constraints and complexities.
- Use analytical and data-driven tools to design, test, and evaluate process-improvement across key healthcare functions such as patient flow, resource utilization, staffing, capacity planning, and supply chain management.
- Interpret and assess model outputs to understand the impact of operational decisions on service quality, system performance, and overall healthcare delivery effectiveness, including applications in emergency service planning.

Syllabus of GE - 3(b):

Unit I: Health Care Systems and Services Management (13 hours)
Overview of global health and health care systems, Challenges in health care delivery across diverse populations, Effectiveness, efficiency, and value-based care, Decision-making frameworks in clinical and administrative settings, Distinctive characteristics of health care services and their operational implications, Principles and practices of health care services management.

Unit II: Forecasting in Health Care Operations (8 hours)
Health care demand forecasting, Capacity and resource planning, Forecast information for operational and strategic decision-making in health care services, Decision-making frameworks for service delivery, access, and system responsiveness improvements.

Unit III: Facility Planning in Health Care Operations **(9 hours)**
Location planning methods and their application to health care facility placement and accessibility, Location-allocation optimization models in health service: the p-median problem, location set covering problem, and maximal covering location problem, Facility layout design for enhancing workflow efficiency and patient care productivity, Analysis of basic layout design problems in clinical and support service environments.

Unit IV: **Resource and Operations Optimization in Health Care** **(15 hours)**
Workload management approaches for clinical, diagnostics and support services, Staffing and scheduling strategies to manage patient demand, and service coverage, Productivity assessment and performance indicators in health care operations, Optimization models for resource allocation and capacity planning, Principles of inventory management for pharmaceuticals, consumables, and medical supplies, Queuing theory applications for patient-flow, waiting time and service-time analysis, Introduction to simulation modeling for evaluating operational alternatives and improving health care service delivery.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Anupindi, R., Chopra, S., Deshmukh, S., Van Mieghem, J., & Zemel, E. (2012). *Managing Business Process Flows* (3rd Edition). Prentice Hall.
2. Brandeau, M. L., Sainfort, F., & Pierskalla, W. P. (2005). *Operations Research and Health Care: A Handbook of Methods and Applications*. Springer.
3. Denton, B.T. (2013). *Handbook of Healthcare Operations Management: Methods and Applications*. Springer.
4. Ozcan, Y. A. (2017). *Quantitative Methods in Health Care Management: Techniques and Applications*. John Wiley & Sons.
5. Rahman, S. U., & Smith, D. K. (2000). Use of location-allocation models in health service development planning in developing nations. *European Journal of Operational Research, 123(3), 437-452.* Elsevier.
6. Research articles in journals and reports from the Census of India, WHO, NSSO, UNICEF, etc.

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GENERIC ELECTIVE
GE - 3(c): REVENUE 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		
Revenue Management GE - 3(c)	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To examine the fundamental principles of pricing and the concept of revenue management as an emerging paradigm in managerial practices across various industries.
- To analyse capacity allocation and price-based revenue management models, along with the optimization techniques employed in revenue management.
- To evaluate the application of revenue management across different industry sectors and identify the key factors influencing its successful implementation.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and revise pricing and product availability decisions across multiple selling channels to maximize a firm's profitability.
- Develop, analyse, and solve revenue optimization models and apply them effectively within organizational settings.
- Identify and leverage opportunities for revenue optimization across diverse business environments.

Syllabus of GE - 3(c):

Unit I: Introduction to Pricing and Revenue Management (6 hours)
History of Pricing and Revenue Optimization. Strategies of Price optimization. Conceptual framework of Revenue Management. Booking controls. Revenue management system. Factors affecting revenue management. Role of revenue management in various industries.

Unit II: Price Optimization (15 hours)
Basic Price Optimization: The Price-Response Function, measure of Price sensitivity, Price Response with Competition. Price Differentiation: The Economics and Tactics of Price Differentiation, Calculating Differentiated Prices, Price Differentiation and Consumer Welfare. Optimal Pricing with Supply Constraint, Market Segmentation and Supply Constraints, Variable Pricing.

Unit III: Capacity Allocation in RM **(15 hours)**
Capacity Allocation Models: Littlewood's two class model, capacity allocation for multiple classes (n-class model), expected marginal seat revenue models (EMSR-a and EMSR-b). Capacity allocation for multiple resources: Network Revenue Management and its applicability. Network RM via Linear Programming approach. Overbooking models: overbooking based on service criteria, economic criteria (simple risk-based booking limit model). Overbooking problem with multiple products/classes and multiple resources.

Unit IV: Price based RM and Applications **(9 hours)**
Applicability of dynamic pricing. Markdown pricing. Promotion based pricing. Customized pricing. Implementing RM in various industries - hotels, car rentals, manufacturing, retailing, sports centre, online travel portals, restaurants, freight, railways. Factors critical in making a RM system effective

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Cross, G. R. (1997). *Revenue management: Hard-core tactics for market domination*: by Robert G. Cross. Broadway Books, 1540 Broadway, New York, NY 10036, 1997.
2. Lilien, G. L., Kotler, P., & Moorthy, K. S. (1995). *Marketing models*. Prentice Hall.
3. Nagle, T. T., & Müller, G. (2017). *The strategy and tactics of pricing: A guide to growing more profitably*. Routledge.
4. Phillips, R. L. (2005). *Pricing and revenue optimization*. Stanford University Press.
5. Sfodera, F. (Ed.). (2006). *The spread of yield management practices: the need for systematic approaches*. Springer Science & Business Media.
6. Talluri, K. T., & Van Ryzin, G. J. (2006). *The theory and practice of revenue management* (Vol. 68). Springer Science & Business Media.
7. Yeoman, I., & McMahon-Beattie, U. (Eds.). (2004*). Revenue management and pricing: Case studies and applications*. Cengage Learning EMEA.

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GENERIC ELECTIVE
GE - 3(d): WARRANTY MODELING AND 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		
Warranty Modeling and Analysis (GE - 3(d))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To explain warranty as a critical element in the marketing of products – a concept that is important to both the seller and the buyer of virtually any consumer or commercial product.
- To teach methodology behind formulation of one-dimensional, two-dimensional and extended warranties.
- To teach how to analyze warranty data.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate warranty policies.
- Deal with cost and optimization problems from the manufacturers and buyers' point of view.
- Analyze warranty data.

Syllabus of GE - 3(d):

Unit I: Introduction **(12 hours)**
Products: Product Classification, Product Performance, Product Warranty, Product Reliability; Classification of Warranties: One-Dimensional (1-D) Warranties, Two-Dimensional (2-D) Warranties, Group Warranties, Reliability Improvement Warranties, Extended Warranties; Warranty Data Collection: Types & Sources of Data, Warranty Claims Data.

Unit II: **Models & Techniques** **(12 hours)**
Cost Models for 1-D Warranties- Per Unit Cost: FRW Policy, Renewing FRW Policy, Non-Renewing PRW Policy, Life Cycle Cost Analysis per unit sale: Non-renewing FRW Policy, Non-Renewing PRW Policy. Cost Models for 2-D Warranties – Modeling Failures & Claims (Type-I usage), Warranty Cost Analysis unit – Different Approaches.

Unit III: Extended Warranties **(12 hours)**
System Degradation & Maintenance, Modelling & Analysis of Degradation and Maintenance (1-D Formulations), Extended & Maintenance Service Contracts Cost Analysis – Cost Analysis of Base Warranty, Cost Analysis of Extended Warranty, Cost Analysis of Maintenance Service Contracts, Basics of Lease Contracts.

Unit IV: Warranty Data Analysis and management **(9 hours)**
Analysis of 1-D data using competing risk models, Acceleration Failure Time Models, Proportional Hazard (P-H) models, Regression Models; Analysis of 2-D data – based on usage rate, composite scale, bivariate model formulation, forecasting expected warranty claim; use of warranty data for improving current products and operations, role of warranty data in new product development.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Blischke, W. R, Karim. M. R. and Murthy, D.N.P (2001). *Warranty Data Collection and Analysis*, Springer-Verlag London Ltd.
2. Blischke W. R. and Murthy, D.N.P. (1994). *Warranty cost analysis*. New York: Marcel Dekker.
3. Murthy, D.N.P. and Jack, N. (2014). *Extended Warranties, Maintenance Service, and Lease Contract: Modeling and Analysis for Decision Making*, Springer
4. Thomas, M. U. (2006). *Reliability and Warranties: Methods for Product Development and Quality Improvement*, CRC Taylor and Francis Group, New York.
5. Yang, G. (2007). *Life Cycle Reliability Engineering*, John Wiley & Sons, Inc., Hoboken, New Jersey.

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Discipline Specific Core - Semester IV

DSC - 9: Reliability & Maintenance Theory

DSC - 10: Scheduling Techniques

DISCIPLINE SPECIFIC CORE
DSC - 9: RELIABILITY AND MAINTENANCE 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		
Reliability and Maintenance Theory (DSC - 9)	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To introduce the key concepts and methods in reliability engineering.
- To teach reliability modelling of systems with different configurations along with optimal reliability allocation and redundancy techniques.
- To teach concept of repair and its impact on the performance of the system along with formulation of maintenance and replacement policies.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Develop reliability models for non-repairable systems under various configurations and perform reliability assessment, including optimal system design through reliability and redundancy allocation.
- Model repairable systems using renewal processes, non-homogeneous Poisson processes, and state-space methods.
- Formulate appropriate system maintenance strategies to enhance overall system performance and reliability.

Syllabus of DSC - 9:

Unit I: System Reliability **(9 hours)**
Basics of Reliability. Classes of life distributions based on Notions of Ageing. System Reliability: Reliability of Series, Parallel, Standby, k-out-of-n, Series-Parallel, Parallel -Series configurations and Bridge Structure. Multi-state System-Series and Parallel systems.

Unit II: Optimal Reliability Design Techniques **(10 hours)**
Optimal Reliability Allocation, Redundancy Allocation Problem: Formulation of optimal redundancy problem with a single restriction for a series system.

Unit III: Repairable System Modeling (16 hours)

Types of Repair, Availability theory: Types of Availability measures; Perfect Repair Models: Introduction to Renewal theory, Types of Renewal Processes and their Asymptotic Properties, Reward Renewal Processes Minimal Repair Models: Introduction to Non Homogenous Poisson Process, Power Law Model; State Space Methods: Markovian approach for reliability/ availability analysis of repairable series and parallel systems, systems with dependent components, and various types of standby systems, System Performance Characteristics, Load-Sharing Systems, Semi-Markovian Approach for one unit system reliability analysis.

Unit IV: Maintenance Policies (10 hours)

Corrective Maintenance; Preventive Maintenance, Age Replacement Policy: cost type criterion, Block Replacement Policy: Cost-type criterion. Preventive Maintenance: one-unit system with repair, Maintenance policies with minimal repairs.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Barlow, R. E., & Proschan, F. (1975). *Statistical theory of reliability and life testing*. Holt, Rinehert & Winston Inc.
2. Cox, D. R. (1967). *Renewal theory*. London: Methuen.
3. Gertsbakh, I. (2013). *Reliability theory with applications to preventive maintenance*. Springer.
4. Kapur, P. K., Kumar, S., & Garg, R. (1999). *Contributions to hardware and software reliability*. Singapore: World Scientific.
5. Kuo, W., & Zuo, M. J. (2003). *Optimal reliability modeling: principles and applications*. John Wiley & Sons.
6. Mitov, K. V., & Omey, E. (2014). *Renewal processes*. Springer. Nakagawa, T. (2005). Maintenance theory on reliability. London: Springer-Verlag.
7. Pham, H. (2003). *Handbook of reliability engineering*. London: Springer-Verlag. Rau, J. G. (1970). Optimization and probability in systems engineering. V.N. Reinhold Co.
8. Rausand, M., & Hoyland, A. (2003). *System reliability theory: models, statistical methods, and applications*. John Wiley & Sons.

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DISCIPLINE SPECIFIC CORE
DSC - 10: SCHEDULING TECHNIQUES

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Prerequisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Scheduling Techniques (DSC - 10)	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart a deep understanding of the theories and concepts underlying various scheduling problems in Operations Research.
- To develop knowledge of key areas such as network flow models, project management, and sequencing problems.
- To enhance the ability to apply scheduling and optimization techniques to real-world operational and managerial contexts.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and analyze mathematical models for network flow problems and project networks with deterministic and probabilistic activity durations and critically evaluate project schedules including cost–time trade-offs.
- Manage resources efficiently under operational and project constraints to improve overall system performance.
- Optimize job allocation in multi-machine production systems to minimize total elapsed time.

Syllabus of DSC - 10:

Unit I: Network Scheduling: Fundamentals and Solution Methodology (10 hours)
Graphs and networks, Path, Cycle, Tree and Cut in a network, Node-arc incidence matrix, Excess capacity matrix, Flows in networks, Max flow- Min cut theorem, Flow augmenting path. Linear programming formulation of Maximal flow problem, Minimum cost flow problem, and Multi-commodity flow problem.

Unit II: Network Models and Applications (10 hours)
Shortest path problem, Travelling Salesman problem, Minimum spanning tree, Capacitated Network flow problem, Transhipment problem, Facility location models: Mathematical modelling and solution methodology.

Unit III: Project Scheduling (15 hours)
Project management with known and probabilistic activity times (CPM & PERT), constructing project networks: Gantt chart, Activity on arrow/Activity on node, Various types of floats and their significance, Project crashing, Linear programming formulation of Project crashing, Project updation, Resource constrained project scheduling: Resource levelling & Resource smoothing.

Unit IV: Theory of Sequencing (10 hours)
Flow-shop and Job-shop problems, Johnsons' optimality rule for a general Flow-shop problem, Parallel processing, General n/m Job-shop integer programming formulation.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Ahuja, R. K., Magnanti, T. L., Orlin, J. B., & Reddy, M. R. (1995). *Applications of network optimization. Handbooks in Operations Research and Management Science*. Elsevier.
2. Baker, K. R., & Trietsch, D. (2019). *Principles of sequencing and scheduling*. John Wiley & Sons Inc.
3. Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2010). *Linear programming and network flows*. John Wiley & Sons.
4. Elmaghraby, S. E. (1977). *Activity networks: Project planning and control by network models*. John Wiley & Sons Inc.
5. Ford, L. R., & Fulkerson, D. R. (2015). *Flows in networks*. Princeton University Press.
6. Jensen, P. A., & Barnes, J. W. (1980). *Network flow programming*. John Wiley & Sons Inc.
7. Wiest, J. D., & Levy, F. K. (1977). *Management guide to PERT/CPM: with GERT/PDM/DCPM and other networks*. Prentice-Hall of India Pvt. Ltd.

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

Discipline Specific Elective – Semester IV

DSE - 4(a): Advanced Inventory Management

DSE - 4(b): Advanced Marketing Management

DSE - 4(c): Bayesian Reliability

DSE - 4(d): Logistics and Network Optimization

DSE - 4(e): Numerical Optimization

DSE - 4(f): Operational Research for Public Policy

DSE - 4(g): Pattern Recognition

DSE - 4(h): Portfolio Optimization

DSE - 4(i): Prognostics and Health Management of Systems

DSE - 4(j): Reliability Testing and Prediction

DSE - 4(k): Queueing Networks

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(a): ADVANCED INVENTORY 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		
Advanced Inventory Management (DSE - (4(a))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- Equip students with advanced inventory control techniques and their practical implementation in real-world business scenarios.
- Provide an in-depth understanding of classical and extended inventory management models, including multi-echelon systems.
- Develop students' ability to model, analyze, and apply both deterministic and stochastic inventory models for effective decision-making.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Demonstrate a comprehensive understanding of classical inventory models, their extensions, and advanced frameworks, and apply quantitative tools to analyze inventory costs and determine optimal policies.
- Explain the structure and functioning of multi-echelon inventory systems and their relevance in both academic and practical settings.
- Understand and apply the principles of Material Requirements Planning (MRP) and key concepts in materials management.

Syllabus of DSE - 4(a):

Unit I: Overview of EOQ Model and its Extensions (12 hours)
Types of inventory models. Probabilistic Reorder Point Inventory Models with and without Lead Time. Two bin(S, s) Inventory Policy. Distribution Free Analysis. Minimax Solution of Inventory Models.

Unit II: Multi-echelon Inventory Systems (15 hours)
Two-warehousing Problems in Inventory management. Capacity Expansion Models. Periodic and Continuous Review models. Inventory Management of Deteriorating Items. EOQ with time value of money. Inventory Control under Inflationary Conditions. EOQ with imperfect quality. EOQ with trade credit.

Unit III: Inventory Control in Supply-Chains (9 hours)
Material Requirement Planning (MRP): Approaches and benefits of MRP. Introduction to MRP I and MRP II. Inputs to an MRP system. Dependent Demand, Bill of Material, Determining net Requirement, Time Phased Order Point.

Unit IV: Material Management (9 hours)
System approach to material management, Importance of Material Management. Value Analysis: Objectives, techniques and application of value analysis. Purchasing Function. Codification: Brisch and Kodak systems. Standardization, Classification, Simplification.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Arrow, K. J., Karlin, S., & Scarf, H. E. (1958). *Studies in the mathematical theory of inventory and production*. Stanford University Press.
2. Axsäter, S. (2015). *Inventory control*. Springer.
3. Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.
4. Muckstadt, J.A., & Sapra, A. (2010). Principles *of Inventory Management: When You Are Down to Four, Order More*. Springer-Verlag.
5. Naddor, E. (1966). *Inventory Systems*. Wiley
6. Ploss, G.W. (1985). *Production and Inventory Control-Principle and Techniques.* 2nd Edition. Prentice Hall.
7. Porteus, E. L. (2002). *Foundations of stochastic inventory theory*. Stanford University Press.
8. Schwarz, L. B. (1981). *Multi-level production/inventory control systems: theory and practice*. North Holland.
9. Sherbrooke, C. C. (2004). *Optimal inventory modeling of systems: multi-echelon techniques.* 2nd Edition. Springer.
10. Zipkin, H. P. (2000). *Foundations of Inventory Systems*. McGraw-Hill.

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DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(b): ADVANCED MARKETING 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		
Advanced Marketing Management (DSE - 4(b))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart knowledge of advanced concepts of Marketing Management.
- To make the students understand mathematical modeling skills to bring in an understanding of scientific management in the entire system.
- To impart analytical thinking and nurture managerial discretion in students.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Understand advanced principles of management and the theoretical foundations of new product management.
- Describe concepts related to successive generational modeling in marketing and their strategic implications.
- Gain insight into mathematical models used for analyzing markets and improving managerial decision-making.

Syllabus of DSE - 4(b):

Unit I: Understanding Advancements in Market **(10 hours)**
Theoretical modeling in marketing, the complexity of marketing models, Management Science and Market Response Models; Defining Consumer Behavior, Evolution of consumer behavior as a field of study and its relationship with Marketing, Mathematical models for consumer buying behavior, om ni-channel marketing concept, the buying decision process: the five stages Model, Adoption Process, Uni-modal and multi-modal diffusion models, Market Extensions models and Refinements.

Unit II: Launch and Management of New Market Offerings **(10 hours)**
Introduction to Infusion process, New Product Decisions: From ideation to pre-launch of new products, Post launch activities, Understanding the launch phenomenon, the launch cycle, Product Line Decisions, Successive Generations: Concept and Modeling Framework.

Unit III: Generic Marketing Strategies **(12 hours)**
Defining Market Segmentation, Bases of segmentation, evaluation and targeting marketing segments and related mathematical models, Brand Positioning and differentiation, Stochastic Models of Brand Choice, Introduction to the concept of Warranty Reserves and Analysis

Unit IV: Some Related Modeling Concepts **(13 hours)**
Understanding market behavior using transition time-based modeling, impact of uncertainty on diffusion dynamics, role of Epidemic Modeling Framework in adoption process, Game theory models for promotional effort, effect of Advertising, and other related Mathematical Models, role of convolution process to understand diffusion process.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Lilien, G. L., Kotler, P., & Moorthy, K. S. (2003). *Marketing models* (Eastern Economy ed.). Prentice-Hall of India.
2. Lilien, G. L., & Rangaswamy, A. (2004). *Marketing engineering: Computer-assisted marketing analysis and planning* (Revised 2nd ed.). Trafford Publishing.
3. Kahn, K. B. (2006). *New product forecasting: An applied approach.* M. E. Sharpe.
4. Montgomery, D. B., & Urban, G. L. (1969). *Management science in marketing*. Prentice-Hall.
5. Research articles from journals of national and international repute.

Suggested Readings:

1. Kotler, P., Keller, K. L., Chernev, A., Sheth, J. N., & Shainesh, G. (2025). *Marketing Management* (17th ed.). Pearson.
2. Murdick, R. G. (1971). *Mathematical models in marketing*. Intext Educational Publishers.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(c): BAYESIAN RELIABILITY

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		
Bayesian Reliability (DSE - 4(c))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To acquaint the students with the performance evaluation of complex devices produced by technological advances using Bayesian reliability analyses.
- To explain maintenance policies using Bayesian approach
- To explain Bayesian Reliability Demonstration Testing (BRDT) that enables demonstrating whether a specified reliability has been achieved in a newly designed component or system and Bayesian Hierarchical models that help predicting reliability of new products.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Evaluate system reliability measures using Bayesian approach.
- Evaluate availability measures of repairable systems
- Learn benefits of applying BRDT and Bayesian Hierarchical models.

Syllabus of DSE - 4(c):

Unit I: System Reliability (12 hours)
Basics of Reliability Engineering and Basics of Bayesian Statistics; Coherent Systems, Basic System Configurations: Reliability Block Diagrams and systems' reliability evaluation, Assignment of Prior Distributions: Component Level Priors, System Level Prior, Reliability evaluation of a series system; Reliability evaluation of a parallel system, Reliability design of a parallel system with identical components; Reliability evaluation of k-out-of-n System , Stress-Strength k-out-of-n system.

Unit II: Availability of Maintained Systems (12 hours)
Availability Measures, General Failure Times/General Repair Times: Component Availability, Series System Availability; Exponential Failure Times/Exponential Repair Times: Component Availability, Series System Availability, Parallel System Availability, Standby System Availability; Exponential Failure Times / General Repair Times; Periodic Maintenance in Redundant System.

Unit III: Bayesian Reliability Demonstration Testing (12 hours)
Classical Zero-failure Test Plans for Substantiation Testing; Classical Zero-failure Test Plans for Reliability Testing; Bayesian Zero-failure Test Plan for Substantiation Testing; Bayesian Zero-failure Test Plan for Reliability Testing.

Unit IV: Bayesian Hierarchical Modeling **(9 hours)**
Introduction; Bayesian Hierarchical Binomial Model; Separate One-level Bayesian Models Bayesian Hierarchical Model; Bayesian Hierarchical Weibull Model.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Bansal, A. K. (2007). Bayesian Parametric Inference, Narosa Publishing House, New Delhi.
2. Berger, J. (1985). Statistical Decision Theory and Bayesian Analysis. New York: Springer-Verlag.
3. Martz, H.F. and Waller, R. A. (1982). Bayesian Reliability Analysis, John Wiley & Sons Inc., New York.
4. Liu, Y. and Abeyratne, A.I. (2019). Practical Applications of Bayesian Reliability, John Wiley & Sons Inc., Hoboken, USA.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(d): LOGISTICS AND NETWORK 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		
Logistics and Network Optimization (DSE - 4(d))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To develop conceptual and mathematical understanding of classical and contemporary optimization models applied to logistics, transportation, routing, and network systems.
- To enable students to model and solve complex logistics and distribution problems involving multiple locations, vehicles, routes, and network structures.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and analyze logistics, routing, and network optimization problems with multiple objectives, constraints and decision variables.
- Apply appropriate optimization techniques, including network models, distribution models, and vehicle routing to real-world logistics and transportation systems.
- Use mathematical programming and computational tools to design and evaluate efficient logistics and distribution systems.

Syllabus of DSE - 4(d):

Unit I: Distribution System Models **(8 hours)**
Structure and components of distribution systems, Mathematical formulation of single and multi-stage distribution models, Representation and roles of warehouses and depots, Performance measures and bottleneck identification.

Unit II: Multi-Index Logistics Models **(10 hours)**
Multi-index logistics models: motivation and structure, Representation of logistics decisions using multi-dimensional indices such as location, vehicle, and route, Exact and Heuristic solution methods, Applications including multi-level, multi-product, and multi-modal logistics systems.

Unit III: **Vehicle Routing** **(12 hours)**
Vehicle routing: capacitated, multiple-depot, time-window, and heterogeneous-fleet variants, Heuristic methods including the Nearest Neighbor and Clarke-Wright Savings algorithms, Modeling and analysis of real-world routing applications in logistics, distribution, and transportation planning.

Unit IV: Network Optimization (15 hours)
Foundations of constrained network flow problems: structure, assumptions, objectives and constraints, Formulation of network flow models as single and multi-objective mathematical programming problems, Optimality and duality principles, Flow-augmentation and residual-network concepts, Optimality tests, Network Simplex method, Degeneracy.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Ahuja, R. K., Magnanti, T. L., & Orlin, J. B. (1993). *Network Flows: Theory, Algorithms, and Applications.* Prentice Hall.
2. Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2010). *Linear Programming and Network Flows* (4th Edition). Wiley.
3. Daskin, M. S. (2013). *Network and Discrete Location: Models, Algorithms, and Applications* (2nd Edition). Wiley.
4. Toth, P., & Vigo, D. (2014). *Vehicle Routing: Problems, Methods, and Applications* (2nd Edition). SIAM.
5. Sinha, K. C., & Labi, S. (2007). *Transportation Decision Making*. John Wiley & Sons, Inc.
6. Research articles in journals from SCI/SCIE/SCOPUS Indexed Journals.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(e): NUMERICAL 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		
Numerical Optimization (DSE - 4(e))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To understand the theoretical foundations and computational techniques of numerical optimization, including linear fractional programming, separable programming, nonlinear optimization, and bi-level programming models.
- To learn appropriate solution methods for modelling and solving real-world constrained optimization problems across diverse application domains.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and solve optimization problems using linear fractional and separable programming techniques.
- Apply solution methods for constrained nonlinear optimization problems, including penalty, barrier, and feasible-direction techniques, and implement complementary pivot algorithm for linear and quadratic programming problems.
- Formulate and solve bi-level programming problems using Karush–Kuhn–Tucker (KKT) conditions and appropriate solution methods.

Syllabus of DSE - 4(e):

Unit I: Linear Fractional Programming **(8 hours)**
Linear fractional programming: concept, formulation, properties of optimal solution, Simplex method, Charnes-Cooper variable transformation method, Applications in production, finance, and portfolio selection.

Unit II: Nonlinear Programming Methods **(8 hours)**
Constrained nonlinear programming problems: Penalty function method, Barrier function method, Frank-Wolfe method, Reduced gradient method, Convex simplex method.

Unit III: Separable and Complementarity Programming **(16 hours)**
Separable programming: concept and structure of separable functions, piecewise linear approximation of nonlinear functions, adjacency condition, formulation of approximate linear programming model, Modified Simplex method, convergence, Linear complementarity problem: formulation, properties, relationship to linear and quadratic programming, Complementary pivot algorithm and its variants.

Unit IV: Bi-Level Programming **(13 hours)**
Bi-level programming: concept and hierarchical structure of leader–follower optimization problem, Formulation of linear bi-level programming models, existence and optimality of solutions, KKT optimality conditions, Solution algorithms for linear bi-level programming problems, Applications in economics and transportation.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. BajaIinov, E. B. (2003). *Linear-fractional Programming: Theory, Methods, Applications, and Software*. Springer.
2. Bazara, M. S., Sherali, H. D., & Shetty, C. M. (2006). *Nonlinear Programming-Theory and Algorithms* (3rd Edition). John Wiley & Sons (Indian print).
3. Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical Optimization with Applications*. Narosa Publishing House.
4. Dempe, S. (2002). *Foundations of Bilevel Programming.* Kluwer Academic Publishers.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(f): OPERATIONAL RESEARCH FOR PUBLIC POLICY

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		
Operational Research for Public Policy (DSE - 4(f))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To provide a conceptual understanding of the role of OR techniques in policy formulation, evaluation, and effective resource allocation through optimization and decision models.
- To utilize data-driven decision-making for evidence-based governance and improved policy planning.
- To develop understanding of ethical, participatory, and stakeholder-oriented aspects of policy modelling.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Model and analyze public policy problems using OR techniques and evaluate policy alternatives through cost–benefit and multi-criteria decision models.
- Use data and quantitative methods to support evidence-based public decision-making.
- Interpret model outcomes to promote transparent, equitable, and accountable policymaking.

Syllabus of DSE - 4(f):

Unit I: Operations Research and Policy Modelling Foundations (10 hours)
Scope and relevance of Operational Research (OR) in public policy; evolution of OR from hard quantitative optimization to soft, participatory, and systems-based approaches; distinction between hard OR models (mathematical programming, optimization) and soft OR methods (problem structuring, cognitive mapping, and stakeholder engagement). Decision-making under certainty, risk, and uncertainty; systems approach to governance and analytical frameworks for public decision processes; Cost–Benefit and Cost-Effectiveness Analysis; Social Welfare Optimization and ethical dimensions in policy evaluation.

Unit II: Resource Allocation and Infrastructure Planning (11 hours)
Optimization for public resources allocation; prioritization of public investments, budgeting and project selection; network and facility location models for transportation, housing, and essential services; operational research tools for urban infrastructure and smart-city logistics; community-based and decentralized OR approaches in planning and development policy.

Unit III: OR Applications in Health, Environment, and Social Sectors (12 hours)
Applications of OR in healthcare planning, pandemic management, and vaccination logistics; queuing and service models for hospitals, e-governance, and transport systems; system dynamics and simulation for environmental management, resource sustainability, and climate policy; Multi-Criteria Decision Analysis for social programme evaluation and policy comparison; optimization and modelling for disaster response, waste management, and emission control; integrated use of OR techniques for achieving social and environmental objectives.

Unit IV: Data, Behavioral Decision Making, and Governance Analytics (12 hours)
Data-driven modelling and behavioral approaches to decision-making in governance; integration of quantitative analysis with behavioral insights for improved policy design; predictive modelling for policy forecasting and electoral analysis; voter segmentation, turnout analysis, and campaign optimization; use of AI, data analytics, and digital platforms in evidence-based governance; ethical, transparency, and accountability considerations in analytical modelling; OR contributions to sustainable, inclusive, and citizen-centered policy frameworks.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Loucks, D. P. (2022). *Public systems modeling: Methods for identifying and evaluating alternative plans and policies* (International Series in Operations Research & Management Science, Vol. 318). Springer.
2. Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill.
3. Drèze, J., & Stern, N. (1990). *Policy Reform: Concepts, Analysis, and Implementation*. Oxford University Press.
4. Johnson, M. P. (Ed.). (2012). *Community-based operations research.* Springer.
5. Saltelli, A., & Di Fiore, M. (Eds.). (2023). *The politics of modelling: Numbers between science and policy.* Oxford University Press.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(g): PATTERN RECOGNITION

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		
Pattern Recognition (DSE - 4(g))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart knowledge of concepts related to pattern recognition, including classification techniques, feature selection, and feature extraction methods.
- To develop practical skills in applying clustering and optimization algorithms for analysing data patterns, improving decision-making, and solving real-world problems efficiently.

Learning Outcomes:

Upon successful completion of this course, the student will be able to:
- Explain foundational principles of pattern recognition, including classification, feature engineering, clustering, and dimensionality reduction techniques.
- Apply linear and non-linear classifiers along with PCA, LDA, ICA, DFT, and DWT for supervised learning, and analyze clustering algorithms such as DBSCAN, DENCLUE, Spectral Clustering, and Vector Quantization for pattern discovery.
- Demonstrate practical proficiency in computational and statistical tools for real-world pattern recognition applications.

Syllabus of DSE - 4(g):

Unit I: Classification Techniques **(12 hours)**
Introduction to Pattern Classification; Linear classifiers and discriminant functions; Decision boundaries and hyperplanes; Measure of error of misclassification and Linear Programming (LPP) formulation; Single-layer Perceptron algorithm; Logistic regression; Support Vector Machines (SVM): Hard margin and Soft margin classifiers; Kernel-based nonlinear SVM; Nonlinear classifiers: Polynomial classifiers, Multi-layer Perceptron (MLP); Ensemble classifiers.

Unit II: Feature Selection Techniques **(12 hours)**
Filter and Wrapper methods, Univariate Feature Selection Methods: Fisher Discriminant Ratio, Pearson correlation, Mutual Information, Multivariate selection methods: Divergence, Chernoff Bound and Bhattacharya distance measures, Scatter Matrices, Minimum-redundancy-maximum-relevance criterion, Feature Subset Selection.

Unit III: Feature Extraction and Transform-Based Modeling (11 hours)
Introduction to feature extraction and dimensionality reduction; Singular Value Decomposition, Principal Component Analysis, Linear Discriminant Analysis, Independent Component Analysis, Transform-based methods: Discrete Fourier Transform and Discrete Wavelet Transform.

Unit IV: Advanced Clustering and Optimization-Based Learning Methods (10 hours)
Density based algorithm for large data sets (DBSACN, DENCLUE), Mixture Decomposition schemes, Vector Quantization, Spectral Clustering based on Graph network, and Competitive Learning algorithms, Cluster Validation.

Tutorial component (if any): Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Theodoridis, S., & Koutroumbas, K. (2008). *Pattern recognition* (4th edition). Academic Press.
2. Duda, R. O., Hart, P. E., & Stork, D. G. (2020). *Pattern classification* (2nd edition). Wiley India.
3. Xu, R., & Wunsch, D. C. (2008). *Clustering*. John Wiley & Sons.

Suggested Readings:

1. Fukunaga, K. (1990). *Introduction to statistical pattern recognition* (2nd edition). Academic Press.
2. Bishop, C. M. (2006). *Pattern recognition and machine learning*. Springer.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(h): PORTFOLIO 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		
Portfolio Optimization (DSE - 4(h))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To build a strong conceptual foundation in portfolio theory, emphasizing risk-return trade-off, diversification, and optimal asset allocation strategies.
- To develop analytical and computational skills for portfolio optimization modelling and performance evaluation.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Explain and analyze the concepts of risk, return, and diversification, and evaluate their significance in designing and managing effective investment portfolios.
- Apply analytical and computational techniques along with portfolio optimization models using alternative risk measures and multi-factor asset-pricing frameworks to construct, optimize, and support informed investment decisions.
- Quantitatively assess portfolio performance using evaluation metrics such as the Sharpe ratio, Jensen's Alpha, and Treynor ratio.

Syllabus of DSE - 4(h):

Unit I: Fundamentals of Portfolio Theory (13 hours)
Portfolio management, Asset classes, Risk and return, Expected value, Variance and covariance of asset returns, Diversification and its role in risk reduction, Short selling, Liquidity and Market impact, Mean–variance analysis, Efficient frontier, Alternative risk measures, Applications of hedging in managing portfolio risk.

Unit II: Portfolio Optimization and Evaluation (14 hours)
Markowitz mean-variance model and the Two-fund theorem, Portfolio optimization using alternative risk measures: mean absolute deviation, mean semi-absolute deviation, value at risk, and conditional value at risk, Portfolio allocation based on marginal risk contribution and implied returns, Portfolio performance evaluation using Jensen's Alpha, Sharpe ratio, and Treynor ratio.

Unit III: Capital Asset Pricing **(9 hours)**
Capital asset pricing model: assumptions, derivation, and expected return-beta relationship, Security market line, Capital market line, One-fund theorem, Arbitrage pricing theory.

Unit IV: Index models **(9 hours)**
Index models and multi-factor models for explaining asset returns, Applications of factor models in risk assessment and portfolio construction, Comparison of index-based portfolio approaches with the Markowitz mean–variance framework.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Bartholomew-Biggs, M. (2005). *Nonlinear Optimization with Financial Applications*. Springer.
2. Gupta, P., Mehlawat, M. K., Inuiguchi, M., & Chandra, S. (2014). *Fuzzy Portfolio Optimization: Advances in Hybrid Multi-Criteria Methodologies*. Springer.
3. Lhabitant, F. S. (2007). *Handbook of Hedge Funds*. Wiley.
4. Luenberger, D. G. (2014). *Investment Science* (2nd Edition). Oxford University Press Inc.
5. Markowitz, H. M. (2000). *Mean-Variance Analysis in Portfolio Choice and Capital Markets*. Wiley.

Suggested Readings:

1. Marrison, C. (2002). *The Fundamentals of Risk Measurement*. McGraw Hill.
2. Prigent, J. L. (2007). *Portfolio Optimization and Performance Analysis*. CRC Press.
3. Reilly, F. K., & Brown, K. C. (2012). *Investment Analysis and Portfolio Management* (10th Edition). Cengage Learning.
4. Roman, S. (2004). *Introduction to the Mathematics of Finance: From Risk Management to Options Pricing*. Springer.
5. Sharpe, W. F. (2000). *Portfolio Theory and Capital Markets*. McGraw Hill.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(i): PROGNOSTICS AND HEALTH MANAGEMENT OF SYSTEMS

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		
Prognostics and Health Management of Systems (DSE - 4(i))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- To introduce Prognostics and Health Management (PHM) as a multifaceted discipline that protects components and products, by avoiding unanticipated problems that can lead to performance deficiencies and adverse effects on safety.
- To introduce prognostics as the process of predicting a system's performance.
- To acquaint students with Condition-Based Maintenance (CBM) as a cost-effective maintenance strategy, which helps perform maintenance only when needed, and helps keep complex engineering systems safe.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Use model-based Prognostics Methods for predicting Remaining Useful Life (RUL) of the system.
- Use data-driven based Prognostics Methods for predicting RUL of the system.
- Use condition-based maintenance strategies for health management of systems.

Syllabus of DSE - 4(i):

Unit I: Introduction **(12 hours)**
Reliability and Prognostics, Historical Background, Prognostics and Health Management (PHM) Applications, Benefits of Prognostics: Benefits in Life-Cycle Cost, Benefits in System Design and Development; Benefits in Production, Benefits in System Operation, Benefits in Logistics Support and Maintenance, PHM Metrics; Sensor Systems for PHM.

Unit II: **Model-Based Prognostics** **(9 hours)**
PoF (Physics of Failure) Prognostics: Introduction, Failure Modes, Mechanisms, and Effects Analysis (FMMEA), Nonlinear Least Squares Method; Markov Chain Monte Carlo Sampling Method, Particle Filter Method.

Unit III: Data-Driven Prognostics **(9 hours)**
Introduction, Gaussian Process Regression, Neural Network: Feedforward Neural Network Model; Concept of Remaining Useful Life (RUL); Applications: Battery Degradation Prognostics, Crack Propagation Prognostics; Comparison Between Physics-Based and Data-Based Prognostics.

Unit IV: **System Health Management** **(15 hours)**
Types of Maintenance; Preventive versus condition-based maintenance; P-F (Prevention- Failure) Curve; Bathtub Curve; Condition-Based Maintenance (CBM) Strategies: Single-Unit systems, Multi-Component Systems; RUL and Dynamic Maintenance Policy.

Tutorial component (if any): Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Kim, N-H, An, Dow, and Choi, J-H (2017). *Prognostics and Health Management of Engineering Systems: An Introduction*. Springer International Publishing, Switzerland.
2. Pecht, M.G. (2008*). Prognostics and Health Management of Electronics*- John Wiley & Sons Inc. Publications, USA.
3. Pecht, M.G. and Kang, M. (2018). *Prognostics and Health Management of Electronics-Fundamentals, Machine Learning, and the Internet of Things*. John Wiley & Sons Ltd. UK.
4. Goodman, D., Hofmeister, K.P., and Szidarovszky, F. (2019). *Prognostics and Health Management - A Practical Approach to Improving System Reliability Using Condition-Based Data*. John Wiley & Sons Ltd. UK.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(j): RELIABILITY TESTING AND PREDICTION

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		
Reliability Testing and Prediction (DSE - 4(j))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To explain a product's life cycle and concept of reliability prediction and its uses.
- To teach how to model tests under normal operating conditions and accelerated conditions.
- To teach analysis of data based on one-shot devices- units that are accompanied by an irreversible chemical reaction or physical destruction and can no longer function properly after use, for example, military weapons.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Learn life-data and degradation-data analytic techniques used in manufacturing industries, along with reliability prediction methods for estimating component and system lifetimes.
- Model and plan tests for lifetime and degradation datasets, including those conducted under accelerated environmental conditions.
- Analyze one-shot testing devices and interpret results for reliability assessment.

Syllabus of DSE - 4(j):

Unit I: Introduction **(10 hours)**
Product Life Cycle, Integrating reliability into product's life cycle, Reliability tasks for a typical product life cycle, Reliability Metrics, Product's Life distributions, Hard Failure and Soft Failure, Reliability Prediction: Introduction, Uses, FMEA, FTA, Role of Testing.

Unit II: **Non-Accelerated Tests** **(12 hours)**
Life data analysis with complete, time-censored and failure censored data sets, Degradation data, Relation of Degradation to Failure, Degradation Modelling: Data Driven Models; Models based on Stochastic Processes (Wiener and Gamma Processes).

Unit III: Accelerated Tests (ATs) (14 hours)
Need for Accelerated Tests, Types of Accelerated Tests: Accelerated Life Tests (ALTs) and Accelerated Degradation Tests (ADTs), Types of Stress Schemes-Constant-Stress; Step-Stress; Progressive Stress; Cyclic Stress; Random Stress; and their various combinations, Stress- Life Relationships, Acceleration Factor, Test Plans, constant-stress and step-stress ALT Plans, ALT under periodic inspection, ADT plans under constant-stress and step-stress loadings.

Unit IV: Analysis of One-shot Devices (9 hours)
One shot device testing data, one-shot devices with competing risks, Accelerated Testing using one-shot devices.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Balakrishnan, N., Ling, H.L., and So, H. Y. (2021). *Accelerated Life Testing of one-shot devices – Data Collection and Analysis*, Wiley.
2. Hφyland, A. and M. Rausand (2004). *System Reliability Theory: Models and Statistical Methods, 2nd edition* John Wiley & Sons Inc., Hobokens, New Jersey.
3. Nelson, W.B. (1990). *Accelerated Testing: Statistical Models, Test Plans, and Data Analysis*, John Wiley & Sons Inc., Hoboken, New Jersey.
4. Yang, G. (2007). *Life Cycle Reliability Engineering*, John Wiley & Sons, Inc., Hoboken, New Jersey.

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

DISCIPLINE SPECIFIC ELECTIVE
DSE - 4(k): QUEUEING NETWORKS

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		
Queueing Networks (DSE - 4(k))	**4**	**3**	**1**	**0**	**Graduation**	**Nil**

Learning Objectives:

The Learning Objectives of this course are as follows:
- Understand classifications of queueing networks, their probabilistic foundations, and derive product-form and non-product-form solutions for open and closed networks.
- Apply computational algorithms such as Convolution, Mean Value Analysis, and Norton's Theorem to evaluate network performance and analyze advanced models including multi-class, mixed, and blocking networks.
- Use queueing network theory to model and analyze real-life systems in computing, communication, manufacturing, and service domains.

Learning Outcomes:

Upon successful completion, students will be able to:
- Explain the fundamental principles and mathematical structure of queueing networks and derive/solve balance and traffic equations using key theorems (Jackson's and Gordon–Newell).
- Apply performance-evaluation algorithms including Mean Value Analysis (MVA) and Convolution, and analyze multi-class, blocking, and finite-capacity networks using exact and approximate methods.
- Model and interpret real-world systems across diverse domains using queueing-network frameworks and evaluate their performance effectively.

Syllabus of DSE - 4(k):

Unit I: Fundamentals of Queueing Networks (10 hours)
Introduction to queueing networks – nodes, routing mechanisms, classification (open, closed, mixed); Series (tandem) queues and cyclic queues; Queue output processes; Departure process from M/M/–/– queue; Time reversibility; Reversible Markov chains; Burke's Theorem; Product-form networks: motivation, global and local balance properties; Applications: Multi-stage service facilities, communication channels, manufacturing and healthcare systems.

Unit II: Open Queueing Networks (12 hours)
Structure and assumptions of open networks; Single-class networks; Traffic equations and stability conditions; Open networks of M/M/m type queues; Jackson's Theorem and product-form solutions; Extensions to Jackson's Theorem; Derivation of performance measures – mean queue length, waiting time, throughput, utilization. Applications: Computer and communication systems, call centers, logistics and routing systems.

Unit III: Closed Queueing Networks (12 hours)

Concept of closed networks and fixed customer populations; Gordon–Newell networks and theorem; Convolution algorithm for normalization constant; Mean Value Analysis (MVA) algorithm; Norton's Theorem for closed networks; Comparison of open vs closed networks; Derivation of throughput and response time measures. Applications: Computer job shops, repair/maintenance systems, closed-loop production and service systems.

Unit IV: Advanced Queueing Networks (11 hours)

Multi-class networks and BCMP networks; Mixed open and closed queueing networks; Models of blocking in open and closed networks of finite capacity queues; Approximate analytical methods for finite capacity networks (open and closed); Approximate analysis of open networks of GI/G/m queues using the Queueing Network Analyzer (QNA) approach. Applications: Performance modeling of service systems with limited resources, manufacturing lines with buffers, healthcare operations, and computer networks with congestion.

Tutorial component (if any) - Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Gross, D., Shortle, J. F., Thompson, J. M., & Harris, C. M. (2018). *Fundamentals of Queueing Theory* (5th Edition). Wiley.
2. Bose, S. K. (2002). *An Introduction to Queueing Systems* (1st Edition). Springer, New York.
3. Bolch, G., Greiner, S., de Meer, H., and Trivedi, K. S. (2006). *Queueing Networks and Markov Chains: Modeling and Performance Evaluation with Computer Science Applications* (2nd Edition). John Wiley & Sons, Inc., Hoboken, New Jersey.
4. Mitra, D. (1988). *Analysis of Queueing Networks*. MIT Press.
5. Balsamo, S., De Nitto Persone, V., and Onvural, R. (2001). *Analysis of Queueing Networks with Blocking*. Kluwer Academic Publishers.

Suggested Readings:

1. Medhi, J. (2003). *Stochastic Models in Queueing Theory* (2nd Edition). Academic Press.
2. Chen, H. & Yao, D. D. (2001). *Fundamentals of Queueing Networks: Performance, Asymptotics and Optimization*. Springer-Verlag.
3. Perron, H. G. (1994). *Queueing Networks with Blocking*. Oxford University Press.
4. Kobayashi, H. & Mark, B. L. (2008). *System Modeling and Analysis: Foundations of System Performance Evaluation*. Prentice Hall.
5. Buzacott, J. A. & Shanthikumar, J. G. (1993). *Stochastic Models of Manufacturing Systems*. Prentice Hall.

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Generic Elective - Semester IV

GE - 4(a): Reliability and Maintenance Theory

GE - 4(b): Scheduling Techniques

GENERIC ELECTIVE
GE - 4(a): RELIABILITY AND MAINTENANCE 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		
Reliability and Maintenance Theory (GE - 4(a))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To introduce the key concepts and methods in reliability engineering.
- To teach reliability modelling of systems with different configurations along with optimal reliability allocation and redundancy techniques.
- To teach concept of repair and its impact on the performance of the system along with formulation of maintenance and replacement policies.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Develop reliability models for non-repairable systems under various configurations and perform reliability assessment, including optimal system design through reliability and redundancy allocation.
- Model repairable systems using renewal processes, non-homogeneous Poisson processes, and state-space methods.
- Formulate appropriate system maintenance strategies to enhance overall system performance and reliability.

Syllabus of GE - 4(a):

Unit I: System Reliability **(9 hours)**
Basics of Reliability. Classes of life distributions based on Notions of Ageing. System Reliability: Reliability of Series, Parallel, Standby, k-out-of-n, Series-Parallel, Parallel -Series configurations and Bridge Structure. Multi-state System-Series and Parallel systems.

Unit II: Optimal Reliability Design Techniques **(10 hours)**
Optimal Reliability Allocation, Redundancy Allocation Problem: Formulation of optimal redundancy problem with a single restriction for a series system.

Unit III: Repairable System Modeling (16 hours)
Types of Repair, Availability theory: Types of Availability measures; Perfect Repair Models: Introduction to Renewal theory, Types of Renewal Processes and their Asymptotic Properties, Reward Renewal Processes Minimal Repair Models: Introduction to Non Homogenous Poisson Process, Power Law Model; State Space Methods: Markovian approach for reliability/ availability analysis of repairable series and parallel systems, systems with dependent components, and various types of standby systems, System Performance Characteristics, Load-Sharing Systems, Semi-Markovian Approach for one unit system reliability analysis.

Unit IV: Maintenance Policies (10 hours)
Corrective Maintenance; Preventive Maintenance, Age Replacement Policy: cost type criterion, Block Replacement Policy: Cost-type criterion. Preventive Maintenance: one-unit system with repair, Maintenance policies with minimal repairs.

Tutorial component (if any) – Yes (15 hours)

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Barlow, R. E., & Proschan, F. (1975). *Statistical theory of reliability and life testing*. Holt, Rinehert & Winston Inc.
2. Cox, D. R. (1967). *Renewal theory*. London: Methuen.
3. Gertsbakh, I. (2013). *Reliability theory with applications to preventive maintenance*. Springer.
4. Kapur, P. K., Kumar, S., & Garg, R. (1999). *Contributions to hardware and software reliability*. Singapore: World Scientific.
5. Kuo, W., & Zuo, M. J. (2003). *Optimal reliability modeling: principles and applications*. John Wiley & Sons.
6. Mitov, K. V., & Omey, E. (2014). *Renewal processes*. Springer. Nakagawa, T. (2005). Maintenance theory on reliability. London: Springer-Verlag.
7. Pham, H. (2003). *Handbook of reliability engineering*. London: Springer-Verlag. Rau, J. G. (1970). Optimization and probability in systems engineering. V.N. Reinhold Co.
8. Rausand, M., & Hoyland, A. (2003). *System reliability theory: models, statistical methods, and applications*. John Wiley & Sons.

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GENERIC ELECTIVE
GE - 4(b): SCHEDULING TECHNIQUES

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Prerequisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Scheduling Techniques (GE - 4(b))	4	3	1	0	Graduation	Nil

Learning Objectives:

The Learning Objectives of this course are as follows:
- To impart a deep understanding of the theories and concepts underlying various scheduling problems in Operations Research.
- To develop knowledge of key areas such as network flow models, project management, and sequencing problems.
- To enhance the ability to apply scheduling and optimization techniques to real-world operational and managerial contexts.

Learning Outcomes:

Upon successful completion of this course, students will be able to:
- Formulate and analyze mathematical models for network flow problems and project networks with deterministic and probabilistic activity durations and critically evaluate project schedules including cost–time trade-offs.
- Manage resources efficiently under operational and project constraints to improve overall system performance.
- Optimize job allocation in multi-machine production systems to minimize total elapsed time.

Syllabus of GE - 4(b):

Unit I: Network Scheduling: Fundamentals and Solution Methodology (10 hours)
Graphs and networks, Path, Cycle, Tree and Cut in a network, Node-arc incidence matrix, Excess capacity matrix, Flows in networks, Max flow- Min cut theorem, Flow augmenting path. Linear programming formulation of Maximal flow problem, Minimum cost flow problem, and Multi-commodity flow problem.

Unit II: Network Models and Applications (10 hours)
Shortest path problem, Travelling Salesman problem, Minimum spanning tree, Capacitated Network flow problem, Transhipment problem, Facility location models: Mathematical modelling and solution methodology.

Unit III: Project Scheduling **(15 hours)**
Project management with known and probabilistic activity times (CPM & PERT), constructing project networks: Gantt chart, Activity on arrow/Activity on node, Various types of floats and their significance, Project crashing, Linear programming formulation of Project crashing, Project updation, Resource constrained project scheduling: Resource levelling & Resource smoothing.

Unit IV: Theory of Sequencing **(10 hours)**
Flow-shop and Job-shop problems, Johnsons' optimality rule for a general Flow-shop problem, Parallel processing, General n/m Job-shop integer programming formulation.

Tutorial component (if any) – Yes **(15 hours)**

Tutorials shall focus on structured problem-solving activities aligned with the material covered in lectures, along with academic tasks intended to reinforce theoretical comprehension.

Essential Readings:

1. Ahuja, R. K., Magnanti, T. L., Orlin, J. B., & Reddy, M. R. (1995). *Applications of network optimization. Handbooks in Operations Research and Management Science*. Elsevier.
2. Baker, K. R., & Trietsch, D. (2019). *Principles of sequencing and scheduling*. John Wiley & Sons Inc.
3. Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2010). *Linear programming and network flows*. John Wiley & Sons.
4. Elmaghraby, S. E. (1977). *Activity networks: Project planning and control by network models*. John Wiley & Sons Inc.
5. Ford, L. R., & Fulkerson, D. R. (2015). *Flows in networks*. Princeton University Press.
6. Jensen, P. A., & Barnes, J. W. (1980). *Network flow programming*. John Wiley & Sons Inc.
7. Wiest, J. D., & Levy, F. K. (1977). *Management guide to PERT/CPM: with GERT/PDM/DCPM and other networks*. Prentice-Hall of India Pvt. Ltd.

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