UNIVERSITY OF DELHI
MASTER OF OPERATIONAL RESEARCH
(MOR)
(Effective from Academic Year 2018-19)

PROPOSED SYLLABUS

MOR Revised Syllabus as approved by Academic Council on XXXX, 2018 and Executive Council on YYYY, 2018

CONTENTS

I. About the Department

Operational Research (OR) as a subject was introduced in the University of Delhi in 1963 with the introduction of a two year post graduate programme. A decade later in 1973, the Department of Operational Research was independently set up under the Faculty of Mathematical Sciences. It is the first department to start a post graduate programme in Operational Research in India.

The Department of Operational Research, since its very inception, has been vigorously engaged in research and the Master of Operational Research (MOR) programme at the Department provides unparalleled depth and experience for students in the subject area of Operational Research. The programme prepares students from different backgrounds for rewarding careers as OR Analysts, Data Scientists and Consultants. The two-year programme offers a unique blend of technical courses, practical consulting skills and real world problem solving experience designed to position students for success in today's competitive business world.

In 1994, the Department also introduced the Post Graduate Programme at South Campus, University of Delhi. The Department also offers M.Phil. and Ph.D. programmes in Operational Research.

The cornerstone of the programme is the Industrial Project where every student is matched with an industry partner to consult on a significant operational issue faced by the company. Working closely with the faculty members and project mentors, each student defines the problem to be solved, collects relevant information, builds mathematical models and delivers decision tools and executive level recommendations to the industry partner. The project outcomes are valued so highly by the industry partners that they hire the students to continue their work with them after completing their degree.

II. Introduction to CBCS (Choice Based Credit System)

Choice Based Credit System:

The CBCS provides an opportunity for the students to choose courses from the prescribed courses comprising core, elective/minor or skill-based courses. The courses will be evaluated following the grading system, which is considered to be better than the conventional marks system. Grading system provides uniformity in the evaluation and computation of the Cumulative Grade Point Average (CGPA) based on student's performance in examinations which enables the student to move across institutions of higher learning. The uniformity in evaluation system also enables the potential employers in assessing the performance of the candidates.

Definitions:

(i) 'Academic Programme' means an entire course of study comprising its programme structure, course details, evaluation schemes, etc. designed to be taught and evaluated in a teaching Department/Centre or jointly under more than one such Department/Centre.

(ii) 'Course' means a segment of a subject that is part of an Academic Programme.

(iii) 'Programme Structure' means a list of courses (Core, Elective, Open Elective) that makes up an Academic Programme, specifying the syllabus, credits, hours of teaching, evaluation and examination schemes, minimum number of credits required for successful completion of the programme, etc. prepared in conformity to University Rules, eligibility criteria for admission.

(iv) 'Core Course' means a course that a student admitted to a particular programme must successfully complete to receive the degree and which cannot be substituted by any other course.

(v) 'Elective Course' means an optional course to be selected by a student out of such courses offered in the same or any other Department/Centre.

(vi) 'Open Elective' means an elective course which is available for students of all programmes, including students of the same department. Students of other Department will opt these courses subject to fulfilling of eligibility of criteria as laid down by the Department offering the course.

(vii) 'Credit' means the value assigned to a course which indicates the level of instructions, one-hour lecture per week equals 1 credit, 2 hours practical class per week equals 1 credit. Credit for a practical could be proposed as part of a course or as a separate practical course.

(viii) 'SGPA' means Semester Grade Point Average calculated for individual semester.

(ix) 'CGPA' is Cumulative Grade Points Average calculated for all courses completed by the students at any point of time. CGPA is calculated each year for both the semesters clubbed together.

(x) 'Grand CGPA' is calculated in the last year of the course by clubbing together of CGPA of two years, i.e., four semesters. Grand CGPA is being given to the student in form of a Transcript. For the benefit of the student a formula for the conversion of Grand CGPA into percentage marks is also given in the Transcript.

III. MOR Programme Details

Programme Objectives:

Spanning over a period of two years and spread across four semesters, the programme emphasizes on core, elective and open elective courses along with the industrial project. The Semester-I and II course work stresses on the theoretical aspects for a strong base, while the Semester-III and IV course work highlights specialization electives and the Project Work. Core aim of the programme is to produce good analysts who are well equipped to acquire significant positions in OR groups of business, government and management consulting companies.

Programme Specific Outcomes:

The programme is designed to:

- Apply the analytical and practical skills learned in the course work.
- Inculcate and develop logical reasoning and aptitude to make the students well equipped to work on complex issues.
- Impart comprehensive knowledge and understanding of advanced theoretical fundamentals in Operational Research.
- Equip scholars with state-of-the-art key Research & Developments in Operational Research.
- Provide hands-on training to the students in the form of an Industrial Project, to address some significant operational issue faced by the company.

Programme Structure:

The MOR programme is a two-year course divided into four semesters. A student is required to complete at least 80 credits for the completion of the course and the award of degree.

		Semester	***Semester***
Part-I	First Year	Semester I	Semester II
Part-II	Second Year	Semester III	Semester IV

Course Credit Scheme:

Semester	**Core Courses**			**Open Elective Course**			**Elective Courses**			**Project**			**Total Credits**
	No. of papers	Credits (L+T or P)	**Total Credits**	No. of papers	Credits (L+T or P)	**Total Credits**	No. of papers	Credits (L+T or P)	**Total Credits**	No. of papers	Credits (L+T or P)	**Total Credits**	
I	05	04	**20**	Nil	Nil	**Nil**	Nil	Nil	**Nil**	Nil	Nil	**Nil**	**20**
II	04	04	**16**	01	04	**04**	Nil	Nil	**Nil**	Nil	Nil	**Nil**	**20**
III	03	04	**12**	01	04	**04**	01	04	**04**	Nil	Nil	**Nil**	**20**
IV	Nil	Nil	**Nil**	Nil	Nil	**Nil**	03	04	**12**	01	08	**08**	**20**
Total Credits for the Course			**48**			**08**			**16**			**08**	**80**

- For each Core, Elective and Open Elective Course, there will be 4 lecture hours of teaching per week.
- Open Electives (8 credits).
- Duration of End Semester Examination of each course shall be of 3 hours.

Eligibility for Admission

Admission is done through entrance examination and Interview. The details are as follows:

	Examination passed	Percentage Required
(a)	Any Master's Degree examination of the University of Delhi or an examination recognized as equivalent thereto with at least two papers in Mathematics/ Computer Science/ Statistics/Operational Research at graduation/ higher level.	**55% marks in aggregate**
	OR	
(b)	Any Bachelor's Degree examination under 10+2+3 scheme of examination of the University of Delhi or an examination recognized as equivalent thereto with at least two papers in Mathematics/Computer Science/Operational Research/ Statistics. **1. Applicants who have graduated under 10+2+3 scheme or an equivalent scheme are eligible for admission.** **2. The candidates who are appearing in the final year examination of the degree on the basis of which admission is sought are also eligible to apply.** **Relaxation will be given to the candidates belonging to SC, ST and OBC category as per the University rules**	**55% marks in aggregate**

Note: ***The admissions to MOR shall be finalized by submitting the proof of the eligibility conditions document not later than August 31 of respective Academic Session. Provisional admission of the students, who fail to meet the eligibility conditions and / or fail to submit result of their qualifying degree examination latest by August 31 of respective Academic Session, shall be annulled without any prior notice to the candidate.***

Assessment of Students' Performance and Scheme of Examinations:

1. English shall be the medium of instruction and examination.
2. Assessment of students' performance shall consist of:
   - Internal Assessment (30 Marks): Attendance: 5 Marks, Evaluation by individual faculty members based on Assignments, Class tests, Presentations etc.: 25 Marks.
   - Internal Assessment for a course having practical component (20 Marks): Attendance: 5 Marks, Evaluation by individual faculty members based on Assignments, Class tests, Presentations etc.: 15 Marks.

- Practical Assessment (30 Marks): Practical Examination: 20 Marks, Viva Voce: 5 Marks, Attendance: 5 Marks.
- End of Semester Examination (70 Marks).
- End of Semester Examination for a course having practical component (50 Marks).
- Project Assessment: Project Report: 100 Marks, Viva Voce: 50 Marks, Internal Assessment: 50 Marks.

3. All the assessment will be based on Learning Outcomes for the course.

Pass Percentage & Promotion Criteria:

Pass Percentage: 40% or equivalent grade (as per University rules) in each course. A student must score the minimum passing marks in **each** of the Core, Elective and Open Elective courses.

Part I to Part II Progression:

For promotion to Part II, a student must have passed in at least four of the core courses of Part I.

Policy for re-appearing in Semester Examination:

A student who has to reappear in a paper prescribed for Semester I/III may do so only in odd Semester examination to be held in November/December. A student who has to reappear in a paper prescribed for Semester II/IV may do so only in the even Semester examination to be held in April/May.

Conversion of Marks into Grades:

University rules to be followed.

Grade Points:

University rules to be followed.

CGPA Calculation:

University rules to be followed.

SGPA Calculation:

University rules to be followed.

Grand SGPA Calculation:

University rules to be followed.

Conversion of Grand CGPA into marks:

As notified by competent authority, the formula for conversion of Grand CGPA into marks is: Final percentage of marks = CGPA based on all four semesters x 9.5

Division of Degree into Classes

University rules to be followed.

Attendance Requirement:

University rules to be followed.

Span Period:

No student shall be admitted for the examination for any of the Parts/Semesters after the lap of **four** years from the date of admission to the Part I/Semester I of the MOR Programme.

Guidelines for the Award of Internal Assessment Marks for MOR Programme (Semester Wise)

Internal Assessment carries 30 marks out of which 5 marks are based on attendance, while 25 marks are for evaluation by individual faculty members based on assignments, class tests, presentations etc.

For a course including practical, Internal Assessment carries 20 marks out of which 5 marks are based on attendance, while 15 marks are for evaluation by individual faculty members based on assignments, class tests, presentations etc.

IV. Semester Wise Details of MOR Programme

		Duration (hrs.)	***Sem. Exam Marks***	***Internal Assessment Marks***	***Total Marks***	***Credits***
First Year: Semester I						
Course: MOR101	Linear Programming and Extensions	3	70	30	100	4
Course: MOR102	Inventory Management	3	70	30	100	4
Course: MOR103	Queueing System	3	70	30	100	4
Course: MOR104	Statistics	3	70	30	100	4
Course: MOR105	Python Programming (a) Theory (b) Practical	 3 3	 50	 20	 70 30	4

		Duration (hrs.)	Sem. Exam Marks	Internal Assessment Marks	Total Marks	Credits
First Year: Semester II						
Course: MOR201	Convex and Discrete Optimization	3	70	30	100	4
Course: MOR202	Scheduling Techniques	3	70	30	100	4
Course: MOR203	Marketing Management	3	70	30	100	4
Course: MOR204	Econometric Modeling and Forecasting	3	70	30	100	4
Course: MOR205:	Open Elective: Database Management System and Visual Programming (a) Theory (b) Practical	 3 3	 50	 20	 70 30	4

		Duration (hrs.)	Sem. Exam Marks	Internal Assessment Marks	Total Marks	Credits
Second Year: Semester III						
Course: MOR301	Mathematical Programming	3	70	30	100	4
Course: MOR302	Reliability and Maintenance Theory	3	70	30	100	4
Course: MOR303	Software Engineering	3	70	30	100	4
Course: MOR304	Open Elective (Any one course out of the following): (i) Health Care Management (ii) Revenue Management	 3 3	 70 70	 30 30	 100 100	 4 4
Course: MOR305	Elective (Any one course out of the following): (i) Supply Chain Management (ii) Financial Management	 3 3	 70 70	 30 30	 100 100	 4 4

		Duration (hrs.)	Sem. Exam Marks	Internal Assessment Marks	Total Marks	Credits
Second Year: Semester IV						
Course: MOR401-403	Any three Electives out of the following:					
	(i) Marketing Research	3	70	30	100	4
	(ii) Advanced Inventory Management	3	70	30	100	4
	(iii) Queueing Networks	3	70	30	100	4
	(iv) Quality Management	3	70	30	100	4
	(v) Multicriteria Decision Models	3	70	30	100	4
	(vi) Data Warehousing and Data Mining	3	70	30	100	4
	(vii) Decision Theory	3	70	30	100	4
	(viii) Dynamic Optimization	3	70	30	100	4
	(ix) Portfolio Management	3	70	30	100	4
	(x) Stochastic Processes	3	70	30	100	4
Course: MOR404-405	**Project Work:** The project work shall be carried out with some industry/company under the supervision of faculty members of the department and the report is to be submitted for evaluation by April 30. It shall carry 200 marks.					
	Project Report Viva-Voce		100 50	50	200	8

V. Detailed Syllabi of MOR Programme

Course - MOR101: Linear Programming and Extensions

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

To impart the knowledge of formulation of practical problems using the linear programming method and its extensions, to understand the theoretical basics of different computational algorithms used in solving linear programming and related problems.

Course Learning Outcomes:

Students completing this course will be able to:

- Describe the basic concepts of convex analysis and explain the theoretical foundations of various issues related to linear programming modelling
- Formulate real-world problems as a linear programming model and describe the theoretical workings of the graphical and simplex method, demonstrate the solution process by hand and solver
- Explain the relationship between a linear program and its dual, including strong duality and complementary slackness
- Perform sensitivity analysis to identify the direction and magnitude of change of a linear programming model's optimal solution as the input data change
- Formulate specialized linear programming problems, namely transportation and assignment problems and describe theoretical workings of the solution methods for transportation and assignment problems, demonstrate solution process by hand and solver
- Apply the knowledge of game theory concepts to articulate real-world decision situations for identifying, analyzing, and practicing strategic decisions to counter the consequences
- Demonstrate solution methods including graphs and linear programming to analyze and solve the Two-person, zero-sum games

Contents:

Unit I: Linear independence and dependence of vectors, Basis, Convex sets, Extreme points, Hyperplanes and Halfspaces, Polyhedral sets and cones, Theoretical results based on above concepts.

Unit II: Introduction to Linear Programming, Problem formulations, Theory of simplex method, Simplex algorithm, Revised simplex method, Duality theory, Dual-simplex method, Sensitivity analysis.

Unit III: Transportation problem: Mathematical model, Balanced and unbalanced problems, Degeneracy, Optimality conditions, Methods to find starting solution and optimal solution, Assignment problem: Mathematical model, Balanced and unbalanced problems, Optimality conditions, Hungarian method.

Unit IV: Two-person zero-sum games: Saddle points, Mixed strategies, Fundamental theorem, Computational methods using graphs and linear programming, Introduction to non-zero sum game.

Suggested Readings:

Bazara, M. S., Jarvis, J. J., & Sherali, H. D. (2004). *Linear programming and network flows* (3rd ed.). Wiley.

Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical optimization with applications.* New Delhi: Narosa Publishing House.

Gass, S. I. (1985). *Linear programming- methods and applications* (5th ed.). New York: McGraw Hill (Dover edition 2003 is also available).

Hadley, G. (2002). *Linear programming*. New Delhi: Narosa Publishing House.

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

Ravindran, A., Phillips, D. T., & Solberg, J. J. (2005). *Operations research- principles and practice* (2nd ed.). New Delhi: Wiley India (P.) Ltd. (Indian print).

Taha, H. A. (2007). *Operations research-an introduction* (8th ed.). New Delhi: Pearson Prentice Hall (Indian print).

Thie, P. R., & Keough, G. E. (2008). *An introduction to linear programming and game theory* (3rd ed.). New Jersey: John Wiley & Sons.

Wayne, W. L., & Venkataramanan, M. (2002). *Introduction to mathematical programming (volume 1): applications and algorithms* (4th ed.). California: Brooks-Cole Publishing.

Teaching Plan:

Week 1-3: Basic concepts of convex analysis and related theoretical results, Introduction to linear programming, formulations of various real-world problems such as product mix problem, nutrition problem, blending problem as linear programming problem, assumptions of linear programming, Graphical method.

Week 4-5: Fundamental theorem of linear programming, Basic feasible solutions, Main theorems of Simplex algorithm including optimality conditions.

Week 6-7: Problem solving using Simplex method, Big-M method, Two-phase method and Revised Simplex method.

Week 8-10: Primal-dual relationships, Construction of Dual problems, Duality theorems, Complementary slackness theorem, Dual-Simplex method, Sensitivity analysis related to both parameter and structural changes in linear programming model.

Week 11-13: Mathematical model of Transportation problem, Balanced and unbalanced problems, feasibility and optimality conditions, Degeneracy. North-West Corner method, Method of Column Minima, Method of Row Minima, Method of Matrix Minima, Vogel's Approximation method for finding starting solution, MODI method for finding optimal solution, Mathematical model of Assignment problem, Balanced and unbalanced problems, feasibility and optimality conditions, Hungarian method.

Week 14-15: Introduction to Game Theory, Principles of decision making, Saddle points, Mixed Strategies, Fundamental theorem, Solving Two-person zero-sum game problems using graphical method and linear programming technique.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Describe the basic concepts of convex analysis (ii) Explain the theoretical foundations of various issues related to linear programming modelling	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts (ii) Give extensive examples during lectures. (iii) Give homework assignments (iv) Encourage students to participate in class discussion (v) Encourage students to give short presentation (vi) Encourage students to apply concepts to solve real-world problems using solver	• Hold Class discussion and presentations • Homework assignments • Final exam • Group activities involving students to solve real-world problems using solver • Hold both announced and unannounced quizzes
II	(i) Formulate real-world problems as linear programming model (ii) Describe the theoretical workings of the graphical and simplex method for linear programming and demonstrate their iterations by hand and solver (iii) Explain the relationship between a linear program and its dual, including strong duality and complementary slackness (iv) Perform sensitivity analysis to identify the direction and magnitude of change of a linear programming model's optimal solution as the input data change		
III	(i) Formulate the specialized linear programming problems like the transportation and assignment problems (ii) Describe the theoretical workings of the solution methods for transportation and assignment problems and demonstrate their working by hand and solver		
IV	(i) Apply the knowledge of game theory concepts to		

	articulate real-world decision situations wherein it is required to identify, analyze, and practice to make strategic decisions to counter the consequences (ii) Demonstrate solution methods including graphs and linear programming to analyze and solve the Two-person, Zero-sum games		

Course - MOR102: Inventory Management

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

In this course students will find insightful discussions about the role of inventory in organizations and core concepts of inventory management. This course gives detailed explanations about fundamental inventory control procedures and their usage. The objectives of this course are to provide students with a thorough understanding of basic inventory models; a rigorous mathematical framework to develop mathematical models to analyse and optimize inventory systems. The course also aims in providing the students with a comprehensive study of various application areas of inventory models through case studies and relevant examples.

Course Learning Outcomes:

Students completing this course will be able to:

- Identify the goals and objectives of inventory management and describe the importance of stocks in an organization and the reasons for holding stock.
- Explain the various costs related to inventory system.
- Understand the various selective inventory control techniques and its applications.
- Capability to develop deterministic inventory models: economic order quantity and its extensions, All units and incremental quantity discounts models, Joint and Individual order policies, Production scheduling models.
- Understand and develop stochastic inventory models and setting safety stocks
- To apply and extend inventory models to analyse real world systems.

Contents:

Unit I: Introduction to Inventory Systems: Analytical structure of Production and Inventory problems. Objectives of Inventory management. Factors influencing inventories. Inventory related costs. Properties of Inventory systems. Selective Inventory control techniques and its applications. Concept of Lead time. Introduction to Just in Time (JIT) and Vendor Managed Inventory (VMI).

Unit II: Deterministic Inventory Models: Deterministic inventory models, economic order quantity and its extensions: without and with lead time. Finite replenishment rate Inventory models without and with planned shortages. Inventory models with partial backlogging and lost sales. Discrete demand Model. Multi-item Inventory models with constraints. Quantity discounts: All units and incremental. Joint and Individual Ordering Policies.

Unit III: Production Planning Models: Aggregate Production Planning Models: Fixed work force model. Variable work force model. Dynamic lot size models: Wagner-Whitin Algorithm, Silver-Meal heuristic.

Unit IV: Stochastic Inventory Models: Stochastic Inventory models, Newsvendor model and its extensions: Instantaneous and uniform demand with discrete and continuous cases; without and with lead time. Transformations for the equivalence of instantaneous and uniform demand models. Power demand pattern inventory model. Periodic review models. Safety stocks, Service levels and reorder level.

Suggested Readings:

Axsäter, S. (2015). *Inventory control* (3rd ed.). Springer.

Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.

Johnson, L. A., & Montgomery, D. C. (1974) *Operations research in production planning, scheduling and inventory control*. New York: Wiley.

Muckstadt, J. A., & Sapra, A. (2010). *Principles of inventory management: when you are down to four, order more.* Springer-Verlag.

Naddor, E. (1966). *Inventory systems*. Wiley.

Silver, E. A., Pyke, D. F., & Peterson, R. (1998). *Inventory management and production planning and scheduling*. (3rd ed.). Wiley.

Waters, D. (2008). *Inventory control and management* (2nd ed.). John Wiley & Sons.

Zipkin, H. P. (2000). *Foundations of inventory systems*. McGraw-Hill.

Teaching Plan:

Week 1-3: Introduction to Inventory management. Basic concepts and terminology related to Inventory system. Objectives of Inventory Control. Factors influencing inventories. Various costs related to Inventory system. Selective Inventory control techniques and its applications. Concept of Lead time. Introduction to Just in Time (JIT) and Vendor Managed Inventory (VMI).

Week 4-7: Deterministic inventory models, economic order quantity and its extensions: without and with lead time. Finite replenishment rate Inventory models without and with planned shortages. Inventory models with partial backlogging and lost sales. Discrete demand model.

Week 8-10: Quantity discount models: All units and incremental. Multi-item Inventory models with constraints. Joint and Individual Ordering Policies.

Week 11-12: Aggregate Production Planning Models: Fixed work force model. Variable work force model. Dynamic lot size models: Wagner-Whitin Algorithm, Silver-Meal heuristic.

Week 13-15: Stochastic Inventory models, Newsvendor model and its extensions: Instantaneous and uniform demand with discrete and continuous cases; without and with lead time. Transformations for the equivalence of instantaneous and uniform demand models. Power demand pattern inventory model. Periodic review models. Safety stocks, Service levels and reorder level.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• Identify the goals and objectives of inventory management • Describe the importance of stocks in an organization and the reasons for holding stock. • Explain the various costs related to inventory system. • Understand the various selective inventory control techniques and its applications. • Explain the concept and benefits of JIT and VMI	Group discussion, Class discussion on real world problems, Presentations, Case studies from industries and their solution approach	Weekly Assignment, Class test, Student Presentations, Solving different case studies with the help of LINGO/ Excel Solver, End-term examination
II	• Derive the basic EOQ formula and its sensitivity analysis. • Develop mathematical models for deterministic demand without and with lead time, and determine the optimal order quantity and reorder levels. • Determine optimal inventory policies for Multi-item Inventory models with constraints. • Distinguish between All units and incremental quantity discounts and determine the EOQ for the same in each model.		
III	• Develop the Aggregate Production Planning Models: Fixed work force model. Variable work force model. • Derive the optimal policy for a Dynamic lot sizing models.		
IV	• Understand and develop stochastic inventory models • Calculate safety stocks and reorder levels. • Develop periodic review inventory model		

	• Derive the power demand pattern model.		

Course - MOR103: Queueing System

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

This course aims in providing the students with a rigorous framework with which to model and analyse queueing systems. The main objective is to provide necessary mathematical support and confidence to the students to tackle real life problems. This course explores both theory and application of fundamental and advanced models in this field.

Course Learning Outcomes:

Students completing this course will be able to:

- Deep understanding of the theoretical background of queueing systems.
- To understand and compute quantitative metrics of performance for queueing systems.
- To apply and extend queueing models to analyze real world systems.

Contents:

Unit I: Introduction: Basic concept of Stochastic Processes, Markov Chains and Markov Processes, Introduction to Queueing Models, Characteristics of Queueing Systems, Arrival process and Departure process, System Performance Measures, Queueing Simulation: Data Generation and Book-Keeping.

Unit II: Markovian Queueing Systems: General Birth-Death Processes, Single-Server Queues (M/M/1), Multi-server Queues (M/M/c), Queues with finite capacity (M/M/c/K), Erlang's Loss Formula (M/M/c/c), Queues with Unlimited Service (M/M/∞), Finite-Source Queues, Queues with State-Dependent Service, Queues with Impatience (M/M/1 Balking and M/M/1 Reneging), Transient behavior of queues.

Unit III: Advanced Markovian Queueing Models: Vacation Queueing Models, Queues with Bulk Input ($M^{[X]}/M/1$), Queues with Bulk Service ($M/M^{[Y]}/1$), Erlangian Queueing Models (M/Ek/1 and Ek/M/1), Basic Idea of Queues with Priority Discipline and Queues with Heterogeneous Servers.

Unit IV: Imbedded Markov Chain Models: Concept of Imbedded Markov chains, Queues with General Arrivals or Service pattern (M/G/1, G/M/1, M/D/c).

Unit V: Decision Problems in Queueing Theory: Design and Control Problems in Decision Making.

Suggested Readings:

Bhat, U. N. (2008). *An introduction to queueing theory: modelling and analysis in applications (statistics for industry and technology)*. Boston: Birkhauser.

Cooper, R. B. (1981). *Introduction to queueing theory* (2nd ed.). North Holland.

Cox, D. R., & Smith,W. L. (1991). *Queues*. Chapman and Hall/CRC.
Gross, D., Shortle, J. F., Thompson, J. M., & Harris, C. M. (2008). *Fundamentals of queueing theory* (4th ed.). Wiley.
Kleinrock, L. (1975). *Queueing systems (volume 1): theory*. John Wiley.
Medhi, J. (2002). *Stochastic models in queueing theory* (2nd ed.). Academic Press.
Prabhu, N. U. (2012). *Foundations of queueing theory (international series in operations research & management science)*. Springer.
Satty, T. L. (1983). *Elements of queueing theory with applications*. New York: Dover Publications.

Teaching Plan:
Week 1-2: Basic concept of Stochastic Processes, Markov Chains and Markov Processes, Introduction to Queueing Models, Characteristics of Queueing Systems, Arrival process and Departure process, System Performance Measures, Queueing Simulation: Data Generation and Book-Keeping.
Week 3-7: General Birth-Death Processes, Single-Server Queues (M/M/1), Multi-server Queues(M/M/c), Queues with finite capacity (M/M/c/K), Erlang's Loss Formula (M/M/c/c), Queues with Unlimited Service (M/M/∞), Queues with State-Dependent Service Rates, Queues with Impatience (M/M/1 Balking and M/M/1 Reneging), Finite-Source Queues, Transient behavior of M/M/1/1 and M/M/1/∞ queues.
Week 8-10: Vacation Queueing Models, Bulk Queues ($M^{[X]}$/M/1 and $M/M^{[Y]}$/1), Erlangian Queueing Models (M/Ek/1 and Ek/M/1), Basic Idea of Queues with Priority Discipline and Queues with Heterogeneous Servers.
Week 11-13: Concept of Imbedded Markov chains, M/G/1, G/M/1 and M/D/c queues.
Week 14-15: Design and Control Problems in Queueing Theory.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• Define a queueing system and its various characteristics. • Understand the mathematical modeling of queuieng systems. • Define various system performance measures. • Simulate a queueing system	Group discussions, Class discussions on real life problems, Presentations	Weekly Assignments, Class Tests, Student presentation, End-term examination.
II	• Understand the mathematical modeling of Markovian queues (birth-death models) and compute quantitative metrics of performance.		
III	• Understand the mathematical		

	modeling of advanced Markovian queues (non-birth-death models) and compute quantitative metrics of performance.		
IV	• Understand the concept of imbedded Markov chains and implement them to solve non-Markovian queues.		
V	• Design an optimal queueing system.		

Course - MOR104: Statistics

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

The aim of this course is to acquaint the students with the fundamental concepts of probability and statistics. To provide an understanding of the processes by which real-life statistical problems are analyzed. To develop an understanding of the role of statistics in Operational Research.

Course Learning Outcomes:

Students completing this course will be able to:

- Quantify uncertainty using probability, learn how to find probability using the concepts of random variables and distribution functions, obtain characteristics of the underlying distributions, and study functional relationships between two random variables.
- Know various discrete and continuous probability distributions along with their characteristics and identify the situations where they provide realistic models.
- Learn about sampling and sampling distributions along with their characteristics which will help them analyze the population or phenomenon from which the sample is drawn.
- Learn inferential methods wherein the distributional form of population or phenomenon from which the sample is drawn is either known (parametric) or unknown (nonparametric).

Contents:

Unit I:

- Probability: Probability Axioms; Conditional Probability; Bayes Theorem; Independent Events
- Random Variable; Joint, Marginal and conditional distributions; independent random variables, Transformation of one and two-dimensional random variables.
- Moments: Mean, Variance, Expected value of a function of random variable; conditional expectation; probabilistic inequalities; moment inequalities;

characteristic functions.

- Curve Fitting and Principle of Least Squares. Correlation and Regression: Linear Regression, Karl-Pearson's correlation coefficient

Unit II:

- Discrete Distributions: Degenerate Distribution; Bernoulli and binomial Distributions; Hypergeometric Distribution; Poisson Distribution; Geometric and Negative Binomial Distributions
- Continuous Distributions: Uniform Distribution; Normal Distribution; Exponential and Gamma Distribution; Beta Distribution; Weibull Distribution.
- Limit Theorems: Weak Law of Large Numbers and Central Limit Theorems.

Unit III:

Sampling and Sampling Distributions: Population and Sample; Sampling Techniques; Sample mean; Sample variance and Sample moments; Sampling from Normal Distributions; Distribution of Sample Mean; Chi-Square Distribution; F-distribution; Students t- distribution.

Unit IV:

- Parametric Inference: Problem of Point Estimation; Method of Maximum Likelihood Estimation; Simple and Composite Hypotheses; Likelihood Ratio Tests; Construction of Confidence Intervals.
- Parametric Tests: Normal tests for proportion and mean based on single sample ; Chi-Square test for variability; t-test for single mean; t-test for difference of means; paired t-test; F test for equality of variances
- Nonparametric Tests: Run test for randomness; Chi-square test for goodness of fit; one- sample sign test; Wilcoxon signed- Ranks Test; Median Test; Mann-Whitney U-test.

Suggested Readings:

Dudewicz, E. J., & Misra S. N. (1988). *Modern mathematical statistics*. Wiley.

Feller, W. (2008). *An introduction to probability theory and its applications (volume 1)* (3rd ed.). Wiley.

Fruend, J. E. (2013). *Mathematical statistics with applications* (8th ed.). Pearson Education India.

Goon, A. M., Gupta, A. K., & Dasgupta, B. (1989). *An outline of statistical theory (volume 1)* (2nd ed.). World Press Pvt. Ltd.

Levin, R. I., Masood, H. S., Rubin, S. D., & Rastogi, S. (2017). *Statistics for management* (8th ed.). Pearson Education.

Mood, A. M., Grabill, F. A., & Boes, D. C. (1974). *Introduction to the theory of statistics* (3rd ed.). McGraw Hill.

Rohatgi, V. K., & Ehsanes Saleh, A. K. Md. (2000). *An introduction to probability and statistics* (2nd ed.). Wiley.

Teaching Plan:

Week 1: Probability: Probability Axioms; Conditional Probability; Bayes Theorem; Independent Events.

Week 2-3: Random Variable; Joint, Marginal and conditional distributions; independent random variables, Transformation of one and two-dimensional random variables. Moments: Mean, Variance, Expected value of a function of random variable; conditional expectation; probabilistic inequalities; moment inequalities; characteristic functions.

Week 4: Curve Fitting and Principle of Least Squares. Correlation and Regression: Linear Regression, Karl-Pearson's correlation coefficient.

Week 5-6: Discrete Distributions: Degenerate Distribution; Bernoulli and binomial Distributions; Hypergeometric Distribution; Poisson Distribution; Geometric and Negative Binomial Distributions.

Week 7-8: Continuous Distributions: Uniform Distribution; Normal Distribution; Exponential and Gamma Distribution; Beta Distribution; Weibull Distribution. Limit Theorems: Weak Law of Large Numbers and Central Limit Theorems.

Week 9-11: Sampling and Sampling Distributions: Population and Sample; Sampling Techniques; Sample mean; Sample variance and Sample moments; Sampling from Normal Distributions; Distribution of Sample Mean; Chi-Square Distribution; F-distribution; Students t- distribution.

Week 12-14: Parametric Inference: Problem of Point Estimation; Method of Maximum Likelihood Estimation; Simple and Composite Hypotheses; Likelihood Ratio Tests; Construction of Confidence Intervals. Parametric Tests: Normal tests for proportion and mean based on single sample ; Chi-Square test for variability; t-test for single mean; t-test for difference of means; paired t-test; F test for equality of variances.

Week 15: Nonparametric Tests: Run test for randomness; Chi-square test for goodness of fit; one- sample sign test; Wilcoxon signed- Ranks Test; Median Test; Mann-Whitney U-test.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	Quantify uncertainty using probability, learn how to find probability using the concepts of random variables and distribution functions, obtain characteristics of the underlying distributions, and study functional relationships between two random variables.	Group discussion, Class discussion on applications of statistics to real-world problems, Presentations	• Hold Class discussion and presentations • Homework assignments • Final exam • Group activities involving students to solve real-world problems using solver • Hold both announced and unannounced quizzes
II	Know various discrete and		

	continuous probability distributions along with their characteristics and identify the situations where they provide realistic models.		
III	Learn about sampling and sampling distributions along with their characteristics which will help them analyse the population or phenomenon from which the sample is drawn.		
IV	Learn inferential methods wherein the distributional form of population or phenomenon from which the sample is drawn is either known (parametric) or unknown (nonparametric).		

Course - MOR105: Python Programming

Marks: 70 **Duration: 3 Hrs.**

Course Objectives:

The course aims to introduce the basic and advanced concepts in Python programming so as to equip the students with modern computing skills. The course will familiarize the students with Python's well-organised data structures and its libraries used for creating applications. Python is an ideal language for scripting and rapid application development in many areas on most platforms.

Course Learning Outcomes:

Students completing this course will be able to:

- Learn Syntax and Semantics of Python Programming
- Understand the control structures and create Functions in Python.
- Develop Python programs using core data structures
- Understand the various data structures available in Python programming language and apply them in solving computational problems.
- Implement Object Oriented Programming concepts in Python
- Handle and plot data using Python Libraries.

Contents:

Unit I: Introduction to Python programming

Familiarization with the basics of Python programming, interactive mode and script mode, Structure of a Program, process of writing a program, script execution, debugging-errors.

Identifiers, Keywords, Constants, Variables and data types.

Arithmetic operators, Relational operators, Logical operators, Ternary operator, Bitwise operators. Input and Output Statements, Control Structures.

Introduction to functions*:* modules, built in and user-defined functions: impeding modules, invoking built-in functions.

User defined functions*:* Parameters, scope of variables, passing parameters, void functions and functions returning values.

Unit II: Data Structures (Strings, Lists, Tuples and Dictionary)

Strings: initializing strings and accessing the elements, string operations, built-in string functions and methods.

Lists: concepts of mutable lists, List operations: creating, initializing, accessing, traversing, appending/inserting, searching and deleting elements; list functions (in built and user defined).

Tuples: Concepts of immutable, creating, initializing, accessing elements; tuple assignment, slices, and indexing; tuple functions.

Dictionary: Concept of key-value pair, creating, initializing, accessing, traversing, appending, updating and deleting elements; dictionary functions and methods.

Unit III: Advanced Python Concepts

Classes and Inheritance: Object oriented programming, Class Instances, Methods Classes Examples, Hierarchies, Visualizing the Hierarchy, Adding another class.

Event driven programming, GUI programming.

Introduction to Python libraries- Pandas, NumPy, Matplotlib: Plotting graphs for various mathematical and statistical functions, searching and sorting functions. Different matrix operations using Numpy package.

Exception Handling: Syntax Errors, Exceptions, Exception Errors, User-Defined Exceptions, raising exceptions, handling exceptions, catching exceptions, Try -except - else clause, Try - finally clause.

Suggested Readings:

Dierbach, C. (2012). *Introduction to computer science using python: a computational problem-solving focus*. Wiley Publishing.

Elkner, J., Downey, A. B., & Meyers, C. (2016). *How to think like a computer scientist: learning with python.* Samurai Media Limited, United Kingdom.

Guttag, J. V. (2013). *Introduction to computation and programming using Python*. MIT Press.

Lambert, K. A. (2018). *Fundamentals of python: first programs*. Cengage Learning.

Lutz, M., & Lutz, M. (1996). *Programming python (volume 8)*. O'Reilly Media, Inc.
McKinney, W. (2012). *Python for data analysis: data wrangling with pandas, NumPy, and IPython*. O'Reilly Media, Inc.
Taneja, S., & Kumar, N. (2017). *Python programming: a modular approach*. Pearson.
Thareja, R. (2017). *Python programming using problem solving approach*. Oxford University Press.
VanderPlas, J. (2016). *Python data science handbook: essential tools for working with data*. O'Reilly Media, Inc.

Teaching Plan:

Week 1-2: Familiarization with the basics of Python programming, interactive mode and script mode, Structure of a Program, process of writing a program, script execution, debugging-errors.

Week 3-4: Identifiers, Keywords, Constants, Variables and data types, Arithmetic operators, Relational operators, Logical operators, Ternary operator, Bitwise operators.

Week 5-6: Input and Output Statements, Control Structures.

Week 7-8: Introduction to functions*:* modules, built in and user-defined functions: impeding modules, invoking built-in functions, User defined functions*:* Parameters, scope of variables, passing parameters, void functions and functions returning values.

Week 9-10: Strings: initializing strings and accessing the elements, string operations, built-in string functions and methods.

Lists: concepts of mutable lists, List operations: creating, initializing, accessing, traversing, appending/inserting, searching and deleting elements; list functions (in built and user defined).

Tuples: concepts of immutable, creating, initializing, accessing elements; tuple assignment, slices, and indexing; tuple functions.

Dictionary: concept of key-value pair, creating, initializing, accessing, traversing, appending, updating and deleting elements; dictionary functions and methods.

Week 11-12: Classes and Inheritance: Object oriented programming, Class Instances, Methods Classes Examples, Hierarchies, Visualizing the Hierarchy, Adding another class.

Week 13-15: Introduction to Python libraries- Pandas, NumPy, Matplotlib: Plotting graphs for various mathematical and statistical functions, searching and sorting functions. Different matrix operations using Numpy package.

Exception Handling: Syntax Errors, Exceptions, Exception Errors, User-Defined Exceptions, raising exceptions, handling exceptions, catching exceptions, Try -except - else clause, Try - finally clause.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• Learn Syntax and Semantics of Python Programming	Group discussion, Class discussion on real world	Weekly Assignment, Class test,

	• Implement the Input output statements and control structures in Python. • Develop functions: modules, built in and user-defined functions: impeding modules, invoking built-in functions. • Passing parameters and returning values from functions.	problems, Presentations.	Student Presentations, End-term examination
II	• Develop Python programs using core data structures • Understand the various data structures available in Python programming language and apply them in solving computational problems.		
III	• Implement Object Oriented Programming concepts in Python • Handle and plot data using Python Libraries. • Understand and implement exception handling in Python programming		

Course - MOR201: Convex and Discrete Optimization

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

To impart knowledge of main concepts and methods of discrete optimization, nonlinear (continuous) optimization and goal programming, which allow treating a wide variety of real-world problems arising in science, engineering and management.

Course Learning Outcomes:

Students completing this course will be able to:

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

- Define the dynamic programming technique concepts and demonstrate its applicability in decision making situations, which require to make a sequence of interrelated decisions
- Describe the theoretical workings of the solution method for quadratic programming problem and demonstrate its working by hand and solver
- Define the goal programming technique concepts and demonstrate the formulations of real-world situations as linear goal programming problems
- Describe the theoretical workings of the solution methods for linear goal programming problems and demonstrate their working by hand and solver

Contents:

Unit I: Unconstrained and constrained optimization problems, Types of extrema and their necessary and sufficient conditions, Line search methods, Convex functions and their properties, Optimality conditions, Quadratic programming, Wolfe's method.

Unit II: Integer linear programming: Modeling using pure and mixed integer programming, Branch and bound technique, Gomory's cutting plane algorithm, 0-1 programming problem, E-Bala's additive algorithm.

Unit III: Linear goal programming: Modeling using goal programming, Archimedean goal programming, Preemptive goal programming, Graphical method, Lexicographic simplex method, Goal efficiency, Dynamic programming: Principle of optimality, Multi-stage decision process, Optimal policies for problem involving additive and multiplicative separable returns for objective and constraint functions.

Suggested Readings:

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

Bazara, M. S., Sherali, H. D., & Shetty, C. M. (2006). *Nonlinear programming-theory and algorithms* (3rd ed.). New Delhi: John Wiley & Sons (Indian print).

Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical optimization with applications.* New Delhi: Narosa Publishing House.

Conforti, M., Cornuejols, G., & Zambelli, G. (2014). *Integer programming*, New York: Springer.

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

Luenberger, D. G., & Ye, Y. (2008). *Linear and nonlinear programming* (3rd ed.). New York: Springer.

Ravindran, A., Phillips, D. T., & Solberg, J. J. (2005). *Operations research- principles and practice* (2nd ed.). New Delhi: Wiley India (P.) Ltd. (Indian print).

Taha, H. A. (2007). *Operations research-an introduction* (8th ed.). New Delhi: Pearson Pren tice Hall (Indian print).

Teaching Plan:

Week 1-2: Unconstrained and constrained optimization problems, Types of extrema and their necessary and sufficient conditions, Line search methods.

Week 3-4: Convex functions and their properties, Hessian matrix check for convexity, Lagrange multiplier rule, Karush-Kuhn-Tucker (KKT) optimality conditions.
Week 5-6: Quadratic programming, KKT conditions, Wolfe's method.
Week 7-8: Integer linear programming problems and modeling techniques, Gomory's cutting plane method for all integer and mixed integer linear programming problems.
Week 9-11: Branch and bound technique for all integer and mixed integer linear programming problems, E-Bala's additive algorithm for 0-1 integer linear programming.
Week 12-13: Dynamic programming problems with additive and multiplicative separable returns for objective as well as constraints functions.
Week 14-15: Modeling using goal programming, Archimedean goal programming, Preemptive goal programming, Lexicographic simplex method, Goal efficiency.

Facilitating the achievement of Course Learning Outcomes

<table>
<tr><th>Unit No.</th><th>Course Learning Outcomes</th><th>Teaching and Learning Activity</th><th>Assessment Tasks</th></tr>
<tr><td>I</td><td>(i) Explain the concepts of convex functions, their properties and describe the convex optimization problem
(ii) Define the optimality conditions for unconstrained and constrained optimization problems
(iii) Explain the difference between local and global optimal solutions
(iv) Describe the theoretical workings of the solution method for quadratic programming problem and demonstrate its working by hand and solver</td><td rowspan="2">(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts
(ii) Give extensive examples during lectures.
(iii) Give homework assignments using hand calculations and solver
(iv) Encourage students to participate in class discussion
(v) Encourage students to give short presentation
(vi) Encourage students to apply concepts to solve real-world problems using solver</td><td rowspan="2">• Hold class discussion and presentations
• Homework assignments
• Final exam
• Group activities involving students to solve real-world problems using solver
• Hold both announced and unannounced quizzes</td></tr>
<tr><td>II</td><td>(i) Formulate real-world problems such as assignment, matching, knapsack, capital budgeting, set covering, set partitioning, routing and scheduling as integer linear programming problems
(ii) Describe the theoretical workings of the solution methods for integer linear programming problems and</td></tr>
</table>

	demonstrate their working by hand and solver		
III	(i) Define the goal programming technique concepts and demonstrate the formulations of real-world situations as linear goal programming problems (ii) Describe the theoretical workings of the solution methods for linear goal programming problems and demonstrate their working by hand and solver (iii) Define the dynamic programming technique concepts and demonstrate its applicability in decision making situations, which require to make a sequence of interrelated decisions		

Course - MOR202: Scheduling Techniques

Marks: 100 **Duration: 3 Hrs.**

Course objectives:

The course is aims to provide deep understanding of the theory and concepts of various scheduling problems in the area of operational research, viz. project management, network flows, sequencing problems, and their related real-world applications.

Course learning outcomes:

Students completing this course will be able to:

- To develop mathematical models associated with network flows and related real life applications.
- To find solutions to network flow problems using standard algorithms.
- To analyze a project with deterministic as well as probabilistic activity times.
- To do Critical analysis of project schedule and analyzing the cost-time trade-offs in the context of a project network.
- To manage the resources efficiently under various constraints.
- To deal with the problems of multiple jobs and machines in a production line and determining the optimal allocation of jobs to machines by minimizing total elapsed time.

Contents:

Unit I: Network flow: 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 Max Flow-Min Cut problem.

Unit II: Network flow problems and applications: Minimum cost flow problem, Maximal flow problem, Multi commodity flow problem, Shortest path problem, Travelling Salesman problem, Minimum spanning tree, Capacitated Network flow problem, Transshipment problem, Facility location model: Mathematical modeling and solution methodology.

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

Unit IV: Theory of sequencing: 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.

Suggested Readings:

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.

Baker, K. R., & Trietsch, D. (2013). *Principles of sequencing and scheduling*. John Wiley & Sons.

Ballou, R. H. (2004). *Business logistics: supply chain management* (5th ed.). Prentice Hall.

Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2011). *Linear programming and network flows*. John Wiley & Sons.

Elmaghraby, S. E. (1977). *Activity networks: project planning and control by network models*. John Wiley & Sons.

Ford Jr, L. R., & Fulkerson, D. R. (2015). *Flows in networks*. Princeton University Press.

Jensen, P. A., & Barnes, J. W. (1980). *Network flow programming*. John Wiley & Sons Inc.

Levy, F. K., & Wiest, J. D. (2016). *Management guide to PERT/CPM; with GERT/PDM/DCPM and other networks*. Prentice-Hall of India.

Teaching Plan:

Week 1-3: 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 Max Flow-Min Cut problem. Minimum cost flow problem, Maximal flow problem, Multi commodity flow problem.

Week 4-5: Shortest path problem, Travelling Salesman problem, Minimum spanning tree.

Week 6-7: Capacitated Network flow problem, Transshipment problem, Facility location model: Mathematical modeling and solution methodology.

Week 8-10: PERT and CPM with known and probabilistic activity times, Constructing project networks: Gantt chart, Activity on arrow/Activity on node, Various types of floats and their significance, Updating PERT charts.
Week 11-13: Project crashing, Linear programming formulation of Project crashing, Resource constrained project scheduling: Resource levelling & Resource smoothing.
Week 14-15: 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.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• To develop mathematical models associated with network flows. • To explain the network flow problems and their real life applications.	Group discussion, Class discussion on real life problems, Presentations	Weekly Assignment, Class test, Student Presentation, End-term examination
II	• To find solutions to network flow problems using standard algorithms. • To implement applications of network flow problems in real life.		
III	• To analyze a project with deterministic as well as probabilistic activity times. • To do Critical analysis of project schedule and to explain the significance of various kinds of floats involved in a project network. • To analyze the cost-time tradeoffs in the context of a project network. • To do Statistical analysis for estimating the probability of completing a project on time. • To manage the resources efficiently under various constraints.		
IV	• To deal with the problems of multiple jobs and machines in a		

	production line. • Finding optimal allocation of jobs to machines for sequencing problem with technological ordering of machines as same for all jobs. • Finding optimal allocation of jobs to machines for sequencing problem with technological ordering of machines as different for all jobs.		

Course - MOR203: Marketing Management

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

The objective of this course is to give students an introduction to the basic concepts and principles of Marketing. The course introduces the theories pertaining to market phenomena related with Customer buying behavior, Product and Brand Management, Pricing, Distribution and Promotional strategies. Keeping mathematical modeling at center, this course shall deal with the utility of management science in analyzing and solving marketing problems.

Course Learning Outcomes:

Students completing this course will be able to:

- Provide relevant skills to aid management decision making.
- Learn and develop different analytical perspectives, management decision tools used in businesses
- Understand and appreciate the concept of marketing strategy formulation, implementation, and evaluation
- Understand the market from both producer's and consumer's perspective.
- Mathematically model the innovation diffusion process and do sales forecasting for new products

Contents:

Unit I: Introduction to Marketing Management: 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: Concept of perfect and imperfect competition, Factors influencing consumer buying behavior, Mathematical models for consumer buying behavior, External-Internal influence diffusion model for sales forecasting, Characteristics of a buyer, Difference between adopter and buyer, Adopter categorization.

Unit III: Product & Brand Management: 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.

Unit IV: 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 V: Distribution Management: Channels of distribution, Locating company's warehouses.

Unit VI: Promotion Management: Promotional decisions in the presence of competition. Spatial Allocation of Promotional Effort, Media Allocation of Advertisement, Game theory models for promotional effort, Sales Response to Advertising in Presence of Competition.

Suggested Readings:

Armstrong, G., Adam, S., Denize, S., & Kotler, P. (2014). *Principles of marketing*. Australia: Pearson.

Curtis, A. (2008). *Marketing for engineers, scientists and technologists*. John Wiley & Sons.

Dowling, G. R., & Dowling, G. R. (2004). *The art and science of marketing: marketing for marketing managers*. USA: Oxford University Press.

Hooley G. J., & Hassey, M. K., (1999). *Quantitative methods in marketing.* International Thomson Business Press.

Kotler, P., & Keller, K. L. (2009). *Marketing management*. Prentice-Hall.

Lilien, G. L., Kotler, P., & Moorthy, K. S. (2003). *Marketing models*. Prentice-Hall of India.

Teaching Plan:

Week 1-2 : 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.

Week 3-6: Concept of perfect and imperfect competition, Factors influencing consumer buying behavior, Mathematical models for consumer buying behavior, External-Internal influence diffusion model for sales forecasting, Characteristics of a buyer, Difference between adopter and buyer, Adopter categorization.

Week 7-8: 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.

Week 9-11: Elasticity Concept, marginal Analysis, Factors affecting pricing decision, Pricing methods, Optimal purchasing policies under fluctuating prices, Joint optimization of price, quality and promotional effort.

Week 12: Channels of distribution, Locating company's warehouses.

Week 13-15: Promotional decisions in the presence of competition. Spatial Allocation of Promotional Effort, Media Allocation of Advertisement, Game theory models for promotional effort, Sales Response to Advertising in Presence of Competition.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	The student will get to know about basics of marketing management and the role of marketing manager in a firm and about the requirement of moving from traditional marketing mix to new marketing mix	Classroom lectures & presentations	Home Assignments, Written Examination and student presentations
II	The student shall develop the understanding towards various types of competition that exist in market along with better understanding of consumer needs and wants. The student will be able to understand the art of mathematical modeling for better interpretation about the types of consumers		
III	The student shall develop his understanding towards the product life cycle and product mix strategies. Furthermore, the student shall understand the brand management concept through a mathematical model		
IV	The student will be able to understand the various objectives of setting up the market price and furthermore seek information about certain purchasing polices under fluctuating pricing		
V	Through certain mathematical modeling, the student shall gain information about choosing the best alternate for distribution of products. Furthermore, he will be able to analyze and help the firms in setting up optimal warehouse location		
VI	Through various methodical models, the student will be able to understand the concept of promotion effort allocation, media allocation and regarding sales response because of advertising		

Course-MOR204: Econometric Modeling and Forecasting

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

To impart the knowledge and skills to the methods of econometric and time-series analysis and to demonstrate how business problems can be modeled for inference and forecasting.

Course Learning Outcomes:

Students completing this course will be able to:

- Describe the concepts and issues of econometric and time series analysis and modeling
- Develop linear single-equation econometric models with one and multiple quantitative explanatory variables to address real-world business problems
- Develop linear single-equation econometric models with one and multiple qualitative explanatory variables to address real-world business problems
- Compute and interpret the multiple standard error of estimate and the coefficient of determination and describe a test of hypothesis to determine whether regression coefficients differ from zero
- Describe components of time series analyses and apply various methods of economic and business forecasting in terms of time series data
- Discriminate between stationary, non-stationary time series and demonstrate various models for stationary time series data
- Demonstrate various dynamic models for time series data and simultaneous equations models

Contents:

Unit I: 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: Classical linear regression models (CLRMs): Multiple linear regression, Multiple and partial correlation coefficients, Violating the assumptions of CLRMs: Multicollinearity, Hetreoscedasticity, Autocorrelation, Non-linear regression models, Multivariate logistic regression model.

Unit III: 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: Distributed lag models using Koyck transformation and Almon transformation, Simultaneous equations models: Basic definitions, Identification problem, Estimation, Forecasting from a simultaneous model.

Suggested Readings:

Brockwell, P. J., & Davis, R. A. (2002). *Introduction to time series and forecasting*. New York: Springer.

Dougherty, C. (2011). *Introduction to econometrics* (4th ed.). New York: Oxford University Press.

Johnston, J. (1984). *Econometric methods* (3rd ed.). New York: Mc-Graw Hill.

Koutsoyiannis, A. (2001). *Theory of econometrics* (2nd ed.). New York: Palgrave Macmillan.

Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (1998). *Forecasting: methods and applications* (3rd ed.). New York: John Wiley & Sons Inc.

Montgomery, D. C., Jennings, C. L., & Kulahci, M. (2008). *Introduction to time series analysis and forecasting*. New York: Wiley-Blackwell.

Montgomery, D. C., Peck, E. A., & Vining, G. G. (2012). *Introduction to linear regression analysis* (5th ed.). New York: John Wiley & Sons Inc.

Teaching Plan:

Week 1: 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.

Week 2-5: Classical linear regression models (CLRMs): Multiple linear regression, Multiple and partial correlation coefficients, Violating the assumptions of CLRMs: Multicollinearity, Hetreoscedasticity, Autocorrelation.

Week 6-7: Non-linear regression models.

Week 8: Multivariate logistic regression model.

Week 9-11: Components of time series, Time series decomposition models, Exponential smoothing methods.

Week 12-13: Stationary and non-stationary time series, Consequence of non-stationarity, Detection of non-stationarity, AR time series models, MA models, ARMA models, ARIMA models, Box-Jenkins approach to forecasting.

Week 14-15: Distributed lag models using Koyck transformation and Almon transformation, Simultaneous equations models: Basic definitions, Identification problem, Estimation, Forecasting from a simultaneous model.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Discriminate between various type of data (ii) Describe the concepts and issues of econometric and time series analysis and modeling (iii) Explain how selection bias could lead to misleading	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts	• Hold Class discussion and presentations • Homework assignments • Final exam • Group activities involving students to

	conclusions regarding the relationship between variables	(ii) Give extensive examples during lectures (iii) Give homework assignments (iv) Encourage students to participate in class discussion (v) Encourage students to give short presentation (vi) Encourage students to apply concepts to solve real-world problems	solve real-world problems using solver • Hold both announced and unannounced quizzes
II	(i) Develop linear single-equation econometric models with one and multiple quantitative explanatory variables to address real-world business problems (ii) Develop linear single-equation econometric models with one and multiple qualitative explanatory variables to address real-world business problems (iii) Compute and interpret the multiple standard error of estimate and the coefficient of determination (iv) Construct and interpret confidence and prediction intervals for the dependent variable and describe a test of hypothesis to determine whether regression coefficients differ from zero		
III	(i) Describe components of time series analyses (ii) Apply various methods of economic and business forecasting in terms of time series data (iii) Discriminate between stationary, non-stationary time series and demonstrate various models for stationary time series data		
IV	(i) Demonstrate various dynamic models for time series data (ii) Demonstrate simultaneous equations models		

Course - MOR205: Database Management System & Visual Programming

Marks: 70 **Duration: 3 Hrs.**

Course Objectives:

The objective of the course is to present an introduction to Database Management Systems (DBMS), with an emphasis on how to organize, maintain and retrieve the information; efficiently and effectively from a DBMS. The course shall provide a technical overview of database management systems, that shall enable the students to understand the logical design of the database using data modeling concepts and thereby manipulate any database using SQL. The course will further familiarize the students with Visual BASIC programming language with object-oriented programming principles.

Learning Outcomes:

Students completing this course will be able to:

- Describe the fundamental elements of relational database management systems.
- Utilize a wide range of features available in a DBMS package.
- Analyze database requirements and determine the entities involved in the system and their relationship to one another.
- Develop the logical design of the database using data modeling concepts
- Manipulate a database using SQL.
- Design, create, build, and debug Visual Basic applications.
- Write Visual Basic programs using object-oriented programming techniques
- Write Windows applications using forms, controls, and events.

Contents:

Unit I: Database Management System- Introduction, concepts and architecture, Characteristics, Advantages of Using DBMS, Brief History of Database Application, Data Models, Schemas, Instances, Three-Schema Architecture and Data Independence, Database Languages and Interfaces, Classification of Database Management Systems.

Unit II: Structure of relational databases, Domains, Relations, Relational algebra– fundamental operators and syntax, relational algebra queries, tuple relational calculus.

Unit III: An overview of Database design and Entity-Relationship (ER) Model, ER-diagrams, weak entity sets, Codd’s rules, Relational Schemas, Extended ER Model. Relational database model: Logical view of data, keys, integrity rules. Relational Database design: features of good relational database design, atomic domain and Normalization (1NF, 2NF, 3NF, BCNF).

Unit IV: Basics of SQL, DDL,DML,DCL, structure – creation, alteration, defining constraints – Primary key, foreign key, unique, not null, check, IN operator, Functions aggregate functions, Built-in functions – numeric, date, string functions, set operations, sub-queries, correlated sub-queries, Use of group by, having, order by, join and its types.

Unit V: Transaction concepts, Properties of a transaction, Concurrency Control, Disk Storage, RAID, Query Processing and Optimization, Distributed Databases.

Unit VI: Introduction to Client Server Programming: Visual programming environment, iconic systems and their specifications including syntactic and semantic aspects. Messages and message passing, Programming with graphic devices, Implementation with visual systems. Introduction to Visual Basic.

Suggested Readings:

Dasai, B.C. (1998). *Database System*, BPB.

Date, C. J. (2006). *An introduction to database systems*. Pearson Education India.

Elmasri, R., & Navathe, S. (2011). *Fundamentals of database systems* (6th ed.), Addison-Wesley Publishing Company.

Ramakrishnan, R., & Gehrke, J. (2000). *Database management systems*. McGraw Hill.

Schneider, D. I. (2013). *An introduction to programming using visual basic 2012*. Prentice Hall Press.

Silberschatz, A., Korth, H. F., & Sudarshan, S. (1997). *Database system concepts* (Vol. 4). New York: McGraw-Hill.

Teaching Plan

Week 1-2: Database Management System- Introduction, concepts and architecture, Characteristics, Advantages of Using DBMS, Brief History of Database Application, Data Models, Schemas, Instances, Three-Schema Architecture and Data Independence, Database Languages and Interfaces, Classification of Database Management Systems.

Week 3: Structure of relational databases, Domains, Relations, Relational algebra - fundamental operators and syntax, relational algebra queries, tuple relational calculus.

Week 4-6: An overview of Database design and Entity-Relationship (ER) Model, ER-diagrams, weak entity sets, Codd's rules, Relational Schemas, Extended ER Model. Relational database model: Logical view of data, keys, integrity rules. Relational Database design: features of good relational database design, atomic domain and Normalization (1NF, 2NF, 3NF, BCNF).

Week 7-10: Basics of SQL, DDL,DML,DCL, structure – creation, alteration, defining constraints – Primary key, foreign key, unique, not null, check, IN operator, Functions-aggregate functions, Built-in functions – numeric, date, string functions, set operations, sub-queries, correlated sub-queries, Use of group by, having, order by, join and its types.

Week 11-12: Transaction concepts, Properties of a transaction, Concurrency Control, Disk Storage, RAID, Query Processing and Optimization, Distributed Databases.

Week 13-15: Introduction to Client Server Programming: Visual programming environment, iconic systems and their specifications including syntactic and semantic aspects. Messages and message passing, Programming with graphic devices, Implementation with visual systems. Introduction to Visual Basic.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	The student will get to know about basics of database systems; their characteristics and advantages	Classroom lectures & presentations	Home Assignments, Written Examination and student presentations
II	The student shall understand important concepts pertaining to conceptual modeling and database design. Furthermore, the student will be able to develop understanding towards advanced database concepts		
III	The student will be able to learn various SQL commands and the utility of these commands for practical applications		
IV	The student shall develop his understanding towards basic concepts of Visual Programming		

Course - MOR301: Mathematical Programming

Marks:100 **Duration: 3 Hrs.**

Course Objectives:

To impart knowledge of main concepts and solution methods of nonlinear programming problems and linear complementary problem, which allow treating a wide variety of real-world problems arising in science, engineering and management.

Course Learning Outcomes:

Students completing this course will be able to:

- Explain the concepts of generalized convex functions, their properties and relations among these and define the optimality conditions for nonlinear programming problems using generalized convex functions
- Describe the theoretical workings of the solution methods for linear fractional programming and separable programming problems and demonstrate their working by hand and solver
- Define the dual problems, namely Wolfe dual and Mond-Weir dual for nonlinear programming problems and establish duality relationships between primal-dual problems
- Describe the theoretical workings of the solution methods for nonlinear programming problems and demonstrate their working by hand and solver

- Define the linear complementary problem and explain its applications to primal-dual linear programming pair and quadratic programming problem.
- Describe the theoretical workings of the complementary pivot algorithm for linear complementary problem and demonstrate its working by hand and solver

Contents:

Unit I: Generalized convex functions and their properties, Optimality conditions using generalized convex functions, Saddle point optimality condition, Nonlinear programming duality.

Unit II: Linear fractional programming: Generalized convexity verification, Simplex method, Charne's and Cooper method, Mathematical programming algorithms: Penalty functions method, Barrier functions method, Frank and Wolfe's method, Method of reduced gradient, Convex simplex method.

Unit III: Separable programming: Linear approximation and its solution using modified simplex method, Linear complementary problem: Complementary pivot algorithm and its variants, applications to linear and quadratic programming problems.

Suggested Readings:

BajaIinov, E. B. (2003). *Linear-fractional programming: theory, methods, applications, and software*, New York: Springer.

Bazara, M. S., Sherali, H. D., & Shetty, C. M. (2006). *Nonlinear programming-theory and algorithms* (3rd ed.). New Delhi: John Wiley & Sons (Indian print).

Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical optimization with applications.* New Delhi: Narosa Publishing House.

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

Luenberger, D. G., & Ye, Y. (2008). *Linear and nonlinear programming* (3rd ed.). New York: Springer.

Ravindran, A., Phillips, D. T., & Solberg, J. J. (2005). *Operations research- principles and practice* (2nd ed.). New Delhi: Wiley India (P.) Ltd. (Indian print).

Teaching Plan:

Week 1-2: Generalized convex functions and their properties, Karush-Kuhn-Tucker (KKT) optimality conditions, Saddle point optimality conditions.

Week 3-4: Nonlinear programming duality theory including linear fractional programming and quadratic programming

Week 5-7: Modeling using linear fractional programming, Establishing generalized convexity results in linear fractional programming, Solving linear fractional programming using Simplex method and Charne's & Cooper method.

Week 8-10: Mathematical programming algorithms including Penalty functions method, Barrier functions method, Frank and Wolfe's method, Method of reduced gradient, Convex simplex method.

Week 11-12: Introduction to Separable programming, Linear approximation of separable functions, Modified Simplex method.

Week 13-15: Introduction to linear complementary problem, Applications to linear and quadratic programming problems, Complementary pivot algorithm and its variants to solve linear complementary problem.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Explain the concepts of generalized convex functions, their properties and relations among them (ii) Define the optimality conditions for nonlinear programming problems using generalized convex functions (iii) Define the dual problems, namely Wolfe dual and Mond-Weir dual for nonlinear programming problems and establish duality relationships between primal-dual problems	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts (ii) Give extensive examples during lectures. (iii) Give homework assignments using hand calculations and solver (iv) Encourage students to participate in class discussion (v) Encourage students to give short presentation (vi) Encourage students to apply concepts to solve real-world problems using solver	• Hold class discussion and presentations • Homework assignments • Final exam • Group activities involving students to solve real-world problems using solver • Hold both announced and unannounced quizzes
II	(i) Describe the theoretical workings of the solution methods for linear fractional programming problems and demonstrate their working by hand and solver (ii) Describe the theoretical workings of the solution methods for nonlinear programming problems and demonstrate its working by hand and solver		
III	(i) Describe the theoretical workings of the solution methods for separable programming problems		

	and demonstrate their working by hand and solver (ii) Define the linear complementary problem and explain its applications to primal-dual linear programming pair and quadratic programming problem. (iii) Describe the theoretical workings of the complementary pivot algorithm for linear complementary problem and demonstrate its working by hand and solver		

Course - MOR302: Reliability and Maintenance Theory

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

This Course provides an introduction to the key concepts and methods in reliability engineering. It includes reliability modelling of systems with different configurations along with optimal reliability allocation and redundancy techniques. The concept of repair and its impact on the performance of the system along with formulation of maintenance and replacement policies will be discussed in detail.

Course Learning Outcomes:

Students completing this course will be able to:

- Develop reliability models for non-repairable systems with different configurations along with reliability assessment.
- Understand the concept of optimal system design through Reliability allocation and Redundancy Allocation Techniques.
- Develop models for repairable systems using renewal process , Non Homogenous Poisson Process and State- space method .
- Formulate system maintenance strategies.

Contents:

Unit-I: System Reliability

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 systems-Series and Parallel systems.

Unit-II: Optimal Reliability Design Techniques

Optimal Reliability Allocation, Redundancy Allocation Problem: Formulation of optimal redundancy problem with a single restriction for a series system.

Unit-III: Repair Models

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 Process

Unit-IV: State Space Methods for System Performance Analysis

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-V: Maintenance Policies

Types of Maintenance: 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.

Suggested Readings:

Barlow, R. E., & Proschan, F. (1975). *Statistical theory of reliability and life testing*. Holt, Rinehert & Winston Inc.

Cox, D. R. (1967). *Renewal theory*. London: Methuen.

Gertsbakh, I. (2013). *Reliability theory with applications to preventive maintenance*. Springer.

Kapur, P. K., Kumar, S., & Garg, R. (1999). *Contributions to hardware and software reliability*. Singapore: World Scientific.

Kuo, W., & Zuo, M. J. (2003). *Optimal reliability modeling: principles and applications*. John Wiley & Sons.

Mitov, K. V., & Omey, E. (2014). *Renewal processes*. Springer.

Nakagawa, T. (2005). *Maintenance theory on reliability*. London: Springer-Verlag.

Pham, H. (2003). *Handbook of reliability engineering*. London: Springer-Verlag.

Rau, J. G. (1970). *Optimization and probability in systems engineering*. V.N. Reinhold Co.

Rausand, M., & Hoyland, A. (2003). *System reliability theory: models, statistical methods, and applications*. John Wiley & Sons.

Teaching Plan:

Week 1-4: Basics of Reliability. Classes of life distributions based on Notions of Ageing. System Reliability: Reliability of Series, Parallel, k-out-of-n, Series-Parallel, Parallel -Series, Standby configurations, Bridge Structure. Reliability modelling of Multi-state systems-Series and Parallel system

Week 5-6: Optimal Reliability Allocation and Redundancy Allocation Methods

Week 7-9: Types of Repair, Availability theory, types of Availability measures; Perfect Repair Models: Introduction to Renewal theory, Types of Renewal Processes and their Asymptotic Properties.

Week 10: Minimal Repair Models: Introduction to Non Homogenous Poisson Process, Power Law Process.

Week 11-13: 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.

Week 14-15: Semi-Markovian Approach for one unit system reliability analysis. Formulation of Maintenance Policies.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	To provide an overview of Basics of Reliability. Classes of life distributions, System Reliability modelling for non-repairable multi-component and multi-state systems.	Lectures, Group Discussions and Class Presentations	Class Tests at the end of Each Unit; Fortnightly Home Assignments; Student Presentations; End-Semester Written Exam.
II	To understand the concept of optimal system design through Reliability Allocation and Redundancy Allocation Methods.		
III	To introduce the concept of repair, system availability, types of Repair and their impact on availability of the systems. To understand the concept of perfect repair and Minimal Repair. To discuss Renewal Processes, their Types and Asymptotic Properties, Non Homogenous Poisson Process, Power Law Process.		
IV	To introduce state space methods used for reliability/ availability analysis of multi-component repairable systems with independent components.		

V	To learn the concept of Maintenance Policies (Age, Block. Preventive & Corrective) and Minimal Repair Replacement Policies		

Course - MOR303: Software Engineering

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

This course introduces different approaches to the software development process and issues they attempt to address. Keeping Software testing at center, the course shall deal with various approaches for software project planning, reliability assessment and software quality assurance.

Course Learning Outcomes:

Students completing this course will be able to:

- Understand software development life cycle, its various stages, different approaches for software development such as the waterfall and evolutionary models.
- Know about recent advances in software development process.
- Perform software requirements analysis, system design preparation
- Understand Software Project management activities including planning, scheduling, risk management, etc.
- Understand software testing approaches-unit testing and integration testing, alpha and beta testing, System testing, Functional testing, Structural testing
- Understand quality control and how to ensure good quality software.
- Develop and validate the mathematical models for in software reliability assessment and prediction.
- Understand the concept of multi up-gradation for software maintenance

Contents:

Unit I Introduction: Introduction to Software Engineering, Software Engineering Principles, Software metrics and measurement, monitoring and control, Software development life-cycle Models: Software development life-cycle, Water fall model, prototyping model, Incremental model, Iterative enhancement Model, Spiral model, Open Source Software and its life cycle

Unit II Software Requirement Specification and System Design: Requirements Elicitation Techniques, Requirements analysis, requirements specification, requirements validation, Design Principles: Problem partitioning, abstraction, design specification, Cohesiveness and Coupling

Unit III Software project Management: Project planning, Software Metrics like LOC, Cost estimation using constructive cost models (Basic, Intermediate and Detailed COCOMO), Risk management activities

Unit IV Software Testing: Verification and validation, code inspection, test plan, test case specification. Level of testing: Unit, Integration Testing, Top down and bottom up integration testing, Alpha and Beta testing, System testing and debugging. Functional testing, Structural testing, Software testing strategies

Unit V: Software Reliability: Modeling Software Reliability and its uses, Difference between hardware and software Reliability, Non-homogeneous Poisson Process based models, Imperfect Debugging models, testing effort based modeling, concept of change point, Release Time problems based on Cost Criterion, Reliability Criterion, Cost and Reliability Criteria, Reliability of a modular software, Resource Allocation Problem

Unit VI Software Quality Assurance & Maintenance: Software quality, ISO 9000 certification for software industry, SEI capability maturity model, Software implementation and integration, Software Maintenance models through multi up-gradation concept.

Suggested Readings:

Aggarwal, K. K., & Singh Y. (2005). *Software engineering*, New Age International.

Kapur, P., Pham, H., Gupta, A., & Jha, P. C. (2011). *Software reliability assessment with OR applications*. London: Springer-Verlag.

Pressman, R. S. (2005). *Software engineering: a practitioner's approach*. Palgrave Macmillan.

Wang, H., & Pham, H. (2010). *Reliability and optimal maintenance*. London: Springer-Verlag.

Yamada, S. (2014). *Software reliability modeling: fundamentals and applications*. Tokyo: Springer.

Teaching Plan:

Week 1-3: Introduction to Software Engineering, Software Engineering Principles, Software metrics and measurement, monitoring and control, Software development life-cycle Models: Software development life-cycle, Water fall model, prototyping model, Incremental model, Iterative enhancement Model, Spiral model, Open Source Software and its life cycle

Week 4-6: Requirements Elicitation Techniques, Requirements analysis, requirements specification, requirements validation, Design Principles: Problem partitioning, abstraction, design specification, Cohesiveness and Coupling

Week 7-9: Project planning, Software Metrics like LOC, Cost estimation using constructive cost models (Basic, Intermediate and Detailed COCOMO), Risk management activities

Week 10: Verification and validation, code inspection, test plan, test case specification. Level of testing: Unit, Integration Testing, Top down and bottom up integration testing, Alpha and Beta testing, System testing and debugging. Functional testing, Structural testing, Software testing strategies

Week 11-13: Modeling Software Reliability and its uses, Difference between hardware and software Reliability, Non-homogeneous Poisson Process based models, Imperfect Debugging models, testing effort based modeling, concept of change point, Release Time problems based on Cost Criterion, Reliability Criterion, Cost and Reliability Criteria, Reliability of a modular software, Resource Allocation Problem

Week 14-15: Software quality, ISO 9000 certification for software industry, SEI capability maturity model, Software implementation and integration, Software Maintenance models through multi up-gradation concept.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	The student will get to know about basics of software development life cycle for both; closed and open source software	Classroom lectures & presentations	Home Assignments, Written Examination and student presentations
II	The student shall understand important sub-phases of requirement analysis and design phase		
III	The student will be able to learn various cost estimation models and understand software risk management		
IV	The student will be able to develop understanding towards validation and verification and various types of testing approaches understand the		
V	The student shall develop his understanding towards various NHPP based mathematical models for software reliability prediction. Furthermore, the student will be able to understand the concepts of modeling software reliability under various real life scenarios and study about optimal software release time		
VI	The student will be able to apply the concepts of quality management in determining software quality and understand about the importance of software maintenance		

Course - MOR304(i): Health Care Management

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

To develop skills in analyzing health care systems and processes and solve related problems by integrating quantitative methods and operations research techniques. Applications using common spread sheet software and modeling applications will be emphasized.

Course Prerequisites:

Basic knowledge in operational research, statistics and basic skills in using excel.

Course Learning Outcomes:

Students completing this course will be able to:

- Explain and discuss important issues in health care, including circumstances causing major changes and reforms in health care industry
- Discuss and analyze health-related legal principles including standards, regulation, and risk management
- Analyze health care operations including flow operations, and apply operations research modelling methods to solve related problems
- Develop models to evaluate and improve health care operations using Excel software
- Identify data needs and data sources to assess structures, processes and outcomes of health care systems
- Interpret model output to assess processes and outcomes of care and the potential impact of proposed operational changes on system performance
- Explain planning and managing emergency services in health care
- Explain mathematical modelling of some major health care processes such as staffing, productivity, resource allocation, supply chain and capacity analysis

Contents:

Unit I: Health care management: Worldwide health, Health care delivery challenges, Effective and efficient health care, Decision making in health care, Distinctive characteristics of health care services, Health care services management.

Unit II: Forecasting in health care operations, Analyze and use forecast information in operations and strategic decisions, Decision-making framework in health care services, Location methods and their application to health care facilities, Importance of layout and its relationship to health care productivity, Analyze simple health care layout problems.

Unit III: Workload management systems in health care, Staffing and scheduling, Levels of utilization and coverage factor in health care facilities, Efficient utilization of health care resources, Measures of productivity in health care operations, Optimization modeling of resource allocation in health care organizations, Inventory management in health care operations, Queuing systems and their use in health care services, Simulation modelling in health care services.

Suggested Readings:

Anupindi, R., Chopra, S., Deshmukh, S., Van Mieghem, J., & Zemel, E. (2012). *Managing business process flows.* New Jersey: Prentice Hall.

Brandeau, M. L., Sainfort, F., & Pierskalla, W. P. (2005). *Operations research and health care: a handbook of methods and applications*. Massachusets: Springer.

Denton, B.T. (2013). *Handbook of healthcare operations management: methods and applications*. New York: Springer.

Ozcan, Y. A. (2009). *Quantitative methods in health care management: techniques and applications* (2nd ed.). California: John Wiley & Sons.

Randolph, H. (2013). *Patient flow: reducing delay in healthcare delivery*. Massachusets: Springer.

Research articles in journals and reports from Census of India, WHO, NSSO, UNICEF, etc.

Teaching Plan:

Week 1-2: Worldwide health, Health care delivery challenges, Effective and efficient health care, Decision making in health care, Distinctive characteristics of health care services, Health care services management.

Week 3-4: Forecasting in health care operations, Analyze and use forecast information in operations and strategic decisions.

Week 5-7: Decision-making framework in health care services, Location methods and their application to health care facilities, Importance of layout and its relationship to health care productivity, Analyze simple health care layout problems.

Week 8-9: Workload management systems in health care, Staffing and scheduling, Levels of utilization and coverage factor in health care facilities, Efficient utilization of health care resources, Measures of productivity in health care operations.

Week 10-11: Optimization modeling of resource allocation in health care organizations using linear programming and integer linear programming.

Week 12-15: Inventory management in health care operations, Queuing systems and their use in health care services, Simulation modelling in health care services.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Explain and discuss important issues in health care, including circumstances causing major changes and reforms in health care industry (ii) Discuss and analyze health-related legal principles including	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts (ii) Give extensive examples during lectures. (iii) Give homework	• Hold class discussion and presentations • Homework assignments • Final exam • Group activities involving students to solve real-world

	standards, regulation, and risk management (iii) Analyze health care operations including flow operations	assignments using hand calculations and Excel (iv) Encourage students to participate in class discussion (v) Encourage students to give short presentation (vi) Encourage students to apply concepts to solve real-world problems using Excel	problems using solver • Hold both announced and unannounced quizzes
II	(i) Identify data needs and data sources to assess structures, processes and outcomes of health care systems (ii) Interpret model output to assess processes and outcomes of care and the potential impact of proposed operational changes on system performance (iii) Develop models to evaluate and improve health care operations using Excel software		
III	(i) Apply operations research modelling methods to solve related problems (ii) Explain planning and managing emergency services in health care (iii) Explain mathematical modelling of some major health care processes such as staffing, productivity, resource allocation, supply chain and capacity analysis using Excel software		

Course - MOR304(ii): Revenue Management

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

To study about the different principles of Pricing and concept of Revenue Management that is a relatively new way to carry out the management in different industries. To explain various quantity and price-based RM models and the optimization approaches

to revenue management. To discuss the role of Revenue management in specific industry sectors and its successful implementation.

Course Learning Outcomes:

Students completing this course will be able to:

- Set and update pricing and product availability decisions for a firm across its various selling channels in order to maximize its profitability.
- Develop and solve the models for revenue optimization; and implement it for the firm.
- Identify and exploit opportunities for revenue optimization in different business contexts.

Contents:

Unit I: Price Optimization

History of Pricing and Revenue Optimization. Strategies of Price optimization. Basic Price Optimization: The Price-Response Function, measure of Price sensitivity, Price Response with Competition, Incremental Costs, The Basic Price Optimization Problem.

Price Differentiation: The Economics of Price Differentiation, Limits to Price Differentiation, Tactics for Price Differentiation, Volume Discounts, Calculating Differentiated Prices, Price Differentiation and Consumer Welfare.

Pricing with Constrained Supply: The Nature of Supply Constraints, Optimal Pricing with a Supply Constraint, Market Segmentation and Supply Constraints, Variable Pricing (revenue-maximizing non-linear optimization problem)

Unit II: Revenue Management (RM)

Conceptual framework of revenue management: levels of RM, strategy for RM, booking control. Revenue management system. Demand-management decisions. Factors affecting revenue management. Role of revenue management in various industries.

Unit III: Quantity based RM

Single resource capacity control: types of control, Littlewood's two class model, capacity allocation for multiple classes (n-class model), expected marginal seat revenue models. Over booking models: overbooking based on service criteria, overbooking based on economic criteria (simple risk-based booking limit model). Overbooking problem with multiple products/classes and multiple resources. Capacity allocation for multiple resources i.e. network management. Applicability of network RM, types of networks. Network RM via Linear Programming approach.

Unit IV: Price based RM

Applicability of dynamic pricing. Dynamic Pricing models: Single-Product Dynamic Pricing Without Replenishment, Single-Product Dynamic Pricing with Replenishment. Deterministic and stochastic models with and without capacity constraints. Markdown pricing, discount pricing, Promotion based pricing. Economics of RM.

Unit V: Implementing RM

Applications in real world. Implementing RM in various industries - hotels, car rentals, manufacturing, retailing, sports centre, online travel portals, restaurants, freight, passenger railways. Issues involved in implementing RM. Factors critical in Making a RM system effective

Suggested Readings:

Cross, G. R. (1997). *Revenue management: hard-core tactics for market domination*. New York: Broadway Books.

Lilien, G. L., Kotler, P., & Moorthy, K. S. (1995). *Marketing models*. Prentice Hall.

Nagle, T. T., & Müller, G. (2017). *The strategy and tactics of pricing: a guide to growing more profitably*. Routledge.

Phillips, R. L. (2005). *Pricing and revenue optimization*. Stanford University Press.

Sfodera, F. (Ed.). (2006). *The spread of yield management practices: the need for systematic approaches*. Springer Science & Business Media.

Talluri, K. T., & Van Ryzin, G. J. (2006). *The theory and practice of revenue management* (Vol. 68). Springer Science & Business Media.

Yeoman, I., & McMahon-Beattie, U. (Eds.). (2004). *Revenue management and pricing: case studies and applications*. Cengage Learning EMEA.

Teaching Plan:

Week 1-4: History of Pricing and Revenue Optimization. Strategies of Price optimization. Basic Price Optimization: The Price-Response Function, measure of Price sensitivity, Price Response with Competition, Incremental Costs, The Basic Price Optimization Problem. Price Differentiation: The Economics of Price Differentiation, Limits to Price Differentiation, Tactics for Price Differentiation, Volume Discounts, Calculating Differentiated Prices, Price Differentiation and Consumer Welfare. Pricing with Constrained Supply: The Nature of Supply Constraints, Optimal Pricing with a Supply Constraint, Market Segmentation and Supply Constraints, Variable Pricing (revenue-maximizing non-linear optimization problem)

Week 5-6: Conceptual framework of revenue management: levels of RM, strategy for RM, booking control. Revenue management system. Demand-management decisions. Factors affecting revenue management. Role of revenue management in various industries.

Week 7-10: Single resource capacity control: types of control, Littlewood's two class model, capacity allocation for multiple classes (n-class model), expected marginal seat revenue models. Over booking models: overbooking based on service criteria, overbooking based on economic criteria (simple risk-based booking limit model). Overbooking problem with multiple products/classes and multiple resources. Capacity allocation for multiple resources i.e. network management. Applicability of network RM, types of networks. Network RM via Linear Programming approach.

Week 11-13: Applicability of dynamic pricing. Dynamic Pricing models: Single-Product Dynamic Pricing Without Replenishment, Single-Product Dynamic Pricing with Replenishment. Deterministic and stochastic models with and without capacity constraints. Markdown pricing, discount pricing, Promotion based pricing. Economics of RM.

Week 14-15: Applications in real world. Implementing RM in various industries - hotels, car rentals, manufacturing, retailing, sports centre, online travel portals, restaurants, freight, passenger railways. Issues involved in implementing RM. Factors critical in Making a RM system effective

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• To study about the different principles of Pricing and concept of Revenue Management (RM) • Understand the basic price optimization model • Methods for Calculating Differentiated Prices • Optimize pricing model with supply constraints	Group discussion, Class discussion on real world problems, Presentations, Case studies from industries and their solution approach	Weekly Assignment, Class test, Student Presentations, Solving different case studies with the help of LINGO/ Excel Solver. End-term examination
II	• Identify the goals and objectives of Revenue management • Understand the Conceptual framework of RM • Identify the factors affecting RM.		
III	• To explain various capacity control RM models. • Understand Overbooking problems in RM • Develop Capacity allocation for multiple resources i.e. network management.		
IV	• Understand the applicability of Dynamic Pricing. • Develop various Dynamic Pricing models.		
V	• Application of RM to real world problems • To discuss the role of RM in specific industry sectors and its successful implementation.		

Course - MOR305(i): Supply Chain Management

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

To impart the knowledge of concepts and approaches for supply chain management to tackle the issues and problems related to the management of demand and supply of

goods and services and to develop skills which helps in understanding how the theories relate to practice.

Course Learning Outcomes:

Students completing this course will be able to:

- Explain the theoretical terminologies related to supply chain management such as logistics, value chain, supply chain and concepts like evolution, integration and importance of supply chain, various elements of supply chain and various supply chain processes and describe the concept of Bullwhip effect and how it can be prevented
- Differentiate between inbound and outbound logistics and Explain theoretically MRP and MRP II, JIT, ERP, DRP, DRP II
- Describe in detail the role of customer relationship management, the role of IT in supply chain, supply chain IT framework and coordination in supply chain
- Describe and demonstrate the supplier selection process and sourcing decisions in a supply chain explaining the role and importance of sourcing and supplier relationship management
- Describe in detail the decisions related to in-house logistics management or outsourcing the logistics to third party or fourth party logistics provider
- Describe in detail the aspects related to green supply chain management and sustainability in supply chain along with the concepts of lean manufacturing and agile supply chain
- Demonstrate the application of supply chain analytics which includes descriptive, predictive and prescriptive analytics

Contents:

Unit I: Basics concepts of supply chain and value chain, Evolution of supply chain, Supply chain integration, Important elements of supply chain, Supply chain processes, Bullwhip effect

Unit II: Introduction to supply chain network, Factors influencing supply chain network, Inbound and outbound logistics, Designing the supply chain network, Framework for structuring a supply chain, Transportation network design, MRP, MRP-II

Unit III: Planning and inventory management, JIT, ERP, DRP, DRP-II, Facility location, Customer relationship management, Role of IT in supply chain, Supply chain IT framework, Supply chain coordination

Unit IV: Procurement management, Selection and management of suppliers, Supplier relationship management, Sourcing decisions in a supply chain, Role of sourcing in SC, Third and Fourth Party Logistics

Unit V: Global supply chain, Reverse supply chain, Closed loop supply chain, Green supply chain, Sustainability in supply chain, Lean Manufacturing and Agile supply chain, Supply chain analytics: descriptive, predictive and prescriptive analytics.

Suggested Readings:

Chopra S., & Meindl, P. (2014). *Supply chain management: strategy, planning, and operation* (6th ed.). Pearson Education India: India.

Gupta, S. M. (2013). *Reverse supply chains: issues and analysis*. USA: CRC Press.

Mentzer, J. T. (2004). *Fundamentals of supply chain management: twelve drivers of competitive advantage*. USA: Sage publications.
Ravindran, A. R., & Warsing Jr., D. P. (2012). *Supply chain engineering: models and applications*. USA: CRC Press.
Rushton, P., Croucher, P., & Baker P. (2014). *The handbook of logistics and distribution management: understanding the supply chain*. UK: Kogan Page Publishers.
Simchi-Levi, D. (2005). *Designing and managing the supply chain*. USA: McGraw-Hill.
Sople, V. V. (2011). *Supply chain management: text and cases*. India: Pearson Education India.
Wang, H. F., & Gupta, S. M. (2011). *Green supply chain management: product life cycle approach*. USA: McGraw Hill Professional.

Teaching Plan:
Week 1-2: Basics concepts of supply chain and value chain, Evolution of supply chain, Supply chain integration, Important elements of supply chain, Supply chain processes, Bullwhip effect
Week 3: Participants in a supply chain network, Factors influencing supply chain network, Inbound and outbound logistics
Week 4-5: Designing the supply chain network, Framework for structuring a supply chain, Designing the supply chain network, Framework for structuring a supply chain, Transportation network design, MRP, MRP-II
Week 6: Planning and inventory management, JIT, ERP, DRP, DRP-II
Week 7: Facility location, Customer relationship management
Week 8: Role of IT in supply chain, Supply chain IT framework, Supply chain coordination
Week 9-10: Procurement management, Selection and management of suppliers, Supplier relationship management, Sourcing decisions in a supply chain, Role of sourcing in SC
Week 11: In-house or outsource, Third and Fourth Party Logistics
Week 12-13: Global supply chain, Reverse supply chain, Closed loop supply chain, Green supply chain, Sustainability in supply chain, Lean Manufacturing and Agile supply chain
Week 14-15: Supply chain analytics: descriptive, predictive and prescriptive analytics

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Explain the theoretical terminologies related to supply chain management such as logistics, value chain, supply chain (ii) Explain the evolution, integration and importance of supply chain (iii) Describe in detail the various elements of supply chain and	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the	Hold class discussion and presentations, Homework assignments, Final exam, Group projects involving students to solve real-world problems,

	various supply chain processes (iv) Describe theoretically the concept of Bullwhip effect and how it can be prevented	relevant concepts (ii) Give extensive examples during lectures (iii) Give homework assignments (iv) Encourage the students to give short presentation (v) Encourage the students to participate in class discussion (vi) Encourage the students to apply concepts to solve real-world problems (vii) Encourage the students to follow learning by doing approach (viii) Encourage the students to help fellow classmates	Hold both announced and unannounced quizzes
II	(i) Explain theoretically various concepts related to supply chain network design like participants in a supply chain network, factors influencing supply chain network (ii) Differentiate between inbound and outbound logistics (iii) Demonstrate the process of supply chain network design and transportation network design explaining the framework for structuring a supply chain (iv) Explain theoretically MRP and MRP II		
III	(i) Explain in detail the issues related to operations in supply chain like planning and inventory management, JIT, ERP, DRP, DRP II (ii) Demonstrate the process of facility location (iii) Describe in detail the role of customer relationship management, the role of IT in supply chain, supply chain IT framework and coordination in supply chain		
IV	(i) Explain in detail the issues related to purchasing in supply chain management (ii) Describe and demonstrate the supplier selection process and sourcing decisions in a supply chain explaining the role and importance of sourcing and supplier relationship management (iii) Describe in detail the decisions related to in-house logistics management or outsourcing the logistics to third party or fourth		

	party logistics provider		
V	(i) Explain the concepts related to global supply chain, reverse supply chain and closed loop supply chain (ii) Describe in detail the aspects related to green supply chain management and sustainability in supply chain along with the concepts of lean manufacturing and agile supply chain (iii) Demonstrate the application of supply chain analytics which includes descriptive, predictive and prescriptive analytics		

Course - MOR 305(ii): Financial Management

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

This is an introductory course in finance that focuses on the practical aspects of corporate finance. The course emphasizes the understanding of finance theory and working knowledge of the financial environment in which the firm operates in order to develop appropriate financial strategies. The course also covers application of optimization techniques to financial management problems.

Course Learning Outcomes:

Students completing this course will be able to:

- Identify the objective of the firm, role of managerial finance. Outline the implications of separation of ownership and control.
- Evaluate financial statements using ratio analysis. Apply a variety of time value of money formulae and techniques.
- Discuss the risk-return trade-off and difference between market risk and unique risk. Demonstrate how risk is measured through Capital Asset Pricing Model (CAPM).
- Explain general concepts of valuing financial assets and their characteristics. Calculate the value of debt and equity securities.
- Apply a variety of capital budgeting techniques. Discuss the concept of opportunity cost of capital and weighted average cost of capital (WACC).
- Identify why firms need to invest in net working capital. Explain the costs and benefits of different working capital management financing strategies.
- Outline alternative sources of long-terms funds and contrast operating leverage and financial leverage. Describe factors that influence a firm’s optimal capital structure and contrast the factors that influence a firm’s pay-out policy.

- Identify appropriate Operational Research techniques to apply to practical problems in Financial Decision Making

Contents:

Unit I: Financial Management: Meaning, nature and scope of finance. Financial markets. Financial Management goal: profit vs. wealth maximization. Finance functions: investment, financing and divided decisions. Time Value of Money: Future and Present Value; Ordinary Annuity, Annuity Due and Perpetuity, Effective Annual Interest Rate (EAR), Loan Amortization. Valuation of Securities: Bonds and their Valuation, Bond Yields. Common and Preferred Stocks and their Valuation. Relationship (Trade-off) between risk and return, Capital Asset pricing model. Financial Statements: Balance Sheet, Income Statement, Statement of Cash Flows. Analysis of Financial Statements: Ratio Analysis, Du Pont Equations. Financial Planning and Forecasting: percentage of sales method, AFN Equation, cash budget.

Unit II: Capital Budgeting: Capital Budgeting process, Project Selection. Estimation of project cash flows, Capital Budgeting Techniques: Payback Period Methods, Average rate of return, Net Present Value methods, IRR, Benefit-Cost ratio, Capital rationing. Cost of Capital: Meaning and significance of cost of capital, Cost of debt, Cost of Equity and reserves, Cost of preferred stock, weighted average cost of capital, Factors affecting cost of capital. Long term financing: shares, Debentures, Warrants, Term loans, Lease financing, Hybrid financing, Venture capital financing.

Unit III: Operating and Financial Leverage: Measurement of leverages; Effects of operating and financial leverage on profit, analysing alternate financial Plans, combined leverage. Capital Structure: Introduction, Factors affecting capital structure, Features of an optimal capital structure, Miller Modigliani propositions I and II. Dividend policy: Aspects of dividend policy, practical consideration, forms of dividend policy, share splits.

Unit IV: Working capital management: Concepts, need; Determinants, issues and estimation of working capital, Accounts Receivables Management and factoring, Inventory management, Cash management. Financing of working capital, Source of working capital, Spontaneous Source and Negotiated Source, types of bank finance; commercial papers, other sources. Analytical approach to finance: Application of Operational Research techniques to the problems in Financial Decision Making

Suggested Readings:

Brealey, R., Mgres, S., & Franklin, A. (2017). *Principle of corporate finance* (11th ed.). New York: McGraw Hill.

Brigham, E. F., & Michael, C.E. (2013). *Financial management- theory and practice* (14th ed.). Nashville: South-Western College Pub.

Cornuejols, G. R., & Tutuncu (2007). *Optimization methods in finance.* Cambridge University Press.

Keown, A. J. , Martin, J. D., & Petty, J. W. (2016). *Foundations of finance* (9th ed.). New Jersey: Pearson.

Khan, M. Y., & Jain, P. K. (2014). *Financial management* (7th ed.). New Delhi: Tata McGraw Hill Pub. Co.

Spronk, J. (1981). *Interactive multiple goal programming: application to financial planning.* Leiden: Martinus Nijhoff Publishing.

Van Horne, J. C., & Wachowicz, J. M. (2008). *Fundamentals of financial management* (13th ed.). Harlow: Prentice Hall Inc.

Teaching Plan:

Week 1-2: Financial Management: Meaning, nature and scope of finance. Financial markets. Financial Management goal: profit vs. wealth maximization. Finance functions: investment, financing and divided decisions. Time Value of Money: Future and Present Value; Ordinary Annuity, Annuity Due and Perpetuity, Effective Annual Interest Rate (EAR), Loan Amortization. Valuation of Securities: Bonds and their Valuation, Bond Yields. Common and Preferred Stocks and their Valuation.

Week 3-5: Relationship (Trade-off) between risk and return, Capital Asset pricing model. Financial Statements: Balance Sheet, Income Statement, Statement of Cash Flows. Analysis of Financial Statements: Ratio Analysis, Du Pont Equations. Financial Planning and Forecasting: percentage of sales method, AFN Equation, cash budget.

Week 6-7: Capital Budgeting: Capital Budgeting process, Project Selection. Estimation of project cash flows, Capital Budgeting Techniques: Payback Period Methods, Average rate of return, Net Present Value methods, IRR, Benefit-Cost ratio, Capital rationing

Week 8-9: Cost of Capital: Meaning and significance of cost of capital, Cost of debt, Cost of Equity and reserves, Cost of preferred stock, weighted average cost of capital, Factors affecting cost of capital. Long term financing: shares, Debentures, Warrants, Term loans, Lease financing, Hybrid financing, Venture capital financing.

Week 10-11: Operating and Financial Leverage: Measurement of leverages; Effects of operating and financial leverage on profit, analysing alternate financial Plans, combined leverage. Capital Structure: Introduction, Factors affecting capital structure, Features of an optimal capital structure, Miller Modigliani propositions I and II. Dividend policy: Aspects of dividend policy, practical consideration, forms of dividend policy, share splits.

Week 12-15: Working capital management: Concepts, need; Determinants, issues and estimation of working capital, Accounts Receivables Management and factoring, Inventory management, Cash management. Financing of working capital, Source of working capital, Spontaneous Source and Negotiated Source, types of bank finance commercial paper, other sources. Analytical approach to finance: Application of Operational Research techniques to financial management problems.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• Identify the objective of the firm, role of managerial finance. Outline the implications of separation of ownership and control. • Evaluate financial statements using ratio analysis. Apply a variety of time value of money formulae and techniques. • Discuss the risk-return trade-off and difference between market risk and unique risk. Demonstrate how risk is measured through Capital Asset Pricing Model (CAPM).	Group discussion, Class discussion on real world problems, Presentations, Case studies	Weekly Assignment, Class test, Student Projects and Presentations, Solving different case studies.
II	• Apply a variety of capital budgeting techniques. • Discuss the concept of opportunity cost of capital and weighted average cost of capital (WACC). • Understand the concept of Cost of Capital		
III	• Contrast operating leverage and financial leverage. • Describe factors that influence a firm's optimal capital structure and the factors that influence a firm's Dividend policy.		
IV	• Identify why firms need to invest in net working capital. • Explain the costs and benefits of different working capital management financing strategies. • Explore the Applications of optimization techniques to financial management problems.		

Course - MOR401-403(i): Marketing Research

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

The objective of this course is to give the students an in depth understanding of marketing research and its role in strategic decision making. The course introduces the concepts of marketing research process, research design, measurement and scaling, sampling design, various data analysis techniques relevant to marketing research.

Course Learning Outcomes:

Students completing this course will be able to:

- Understand the role of marketing research in strategic decision making
- Identify various steps involved in marketing research process
- Develop the research objectives and identify the appropriate market research design
- Manage the Data Collection process
- Understand different statistical data analysis techniques that are used in marketing research
- Interpret the data analysis results in the context of marketing problem under study

Contents:

Unit I: Understanding Marketing Research: Concept of Marketing Research and its objectives, Applications of Marketing Research, Defining the marketing research problem and developing an approach**.**

Unit II: **Research Design Formulation:** Planning, Research Design Classification, potential sources of error, exploratory and descriptive research, experimental research.

Unit III: Methods of Data Collection: Primary and Secondary Data collection, advantages and limitations of primary and secondary data, Comparative and Non Comparative Techniques, Measurement and scaling techniques, Questionnaire design process.

Unit IV: Sampling: The sampling design process, classification of sampling techniques; Non-probability sampling techniques and probability sampling techniques, sample size determination.

Unit V: Statistical Techniques for Data Analysis: Data Processing; Testing of hypothesis, Analysis of variance and covariance, MANOVA**,** Discriminant Analysis, Factor Analysis, Cluster Analysis, Conjoint Analysis.

Suggested Readings:

Aaker, D. A., Kumara, V., & Day, G. S. (2007). *Marketing research*. John Wiley & Sons Inc.

Green, P. E., Tull, D. S., & Album, G. (1999). *Research for marketing decisions*: Prentice Hall of India.

Hague, P. N., Hague, N., & Morgan, C. A. (2004). *Market research in practice: a guide to the basics*. Kogan Page Publishers.

Heeringa, S. G., West, B. T., & Berglund, P. A. (2017). *Applied survey data analysis*. Chapman and Hall.

Malhotra, N., Hall, J., Shaw, M., & Oppenheim, P. (2006). *Marketing research: an applied orientation*. Pearson Education.

Smith, S. M., & Albaum, G. S. (2005). *Fundamentals of marketing research*. SAGE Publications Inc.

Teaching Plan:

Week 1: Concept of Marketing Research and its objectives, Applications of Marketing Research, Defining the marketing research problem and developing an approach

Week 2-4: Planning, Research Design Classification, potential sources of error, exploratory and descriptive research, experimental research

Week 5-9: Primary and Secondary Data collection, advantages and limitations of primary and secondary data, Comparative and Non Comparative Techniques, Measurement and scaling techniques, Questionnaire design process, The sampling design process, classification of sampling techniques; Non-probability sampling techniques and probability sampling techniques, sample size determination

Week 10-15: Data Processing; Testing of hypothesis, Analysis of variance and covariance, MANOVA**,** Discriminant Analysis, Factor Analysis, Cluster Analysis, Conjoint Analysis

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	The student will get to know about basics of marketing research and the role of marketing research in decision making	Classroom lectures & presentations	Home Assignments, Written Examination and student presentations
II	The student shall understand definition of research design and its classification into exploratory and descriptive research		
III	The student shall develop the understanding towards the art of data collection followed by learning towards comparative and non-comparative scaling techniques		
IV	The student will be able to understand various design and procedures for sampling		
V	The student will be able to understand basic statistical techniques for data analysis, analyze complex data through		

	advanced statistical tools and learn the principles behind them		

Course - MOR401-403(ii): Advanced Inventory Management

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

The course aims to equip students with advance inventory control techniques, and their implementation in realistic scenarios. The course will provide an in-depth study of classical models for inventory management and their extensions, modelling approaches to multi-echelon inventory systems. The course will cover both deterministic and stochastic inventory models.

Course Learning Outcomes:

Students completing this course will be able to:

- A thorough understanding of classical inventory models and their extension.
- A set of quantitative tools for analysing the costs and optimal solutions for inventory policies in different environment.
- Knowledge of the approaches to multi-echelon inventory systems that have been proposed in the literature
- A sampling of the more complex models that have been developed using classical models as a basis
- An understanding of Material Requirement Planning (MRP).
- Understand the fundamentals of material management.

Contents:

Unit I: Overview of EOQ model and its extensions. 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: 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. Material Requirement Planning (MRP): Approaches and benefits of MRP. Inputs to an MRP system. Dependent Demand, Bill of Material, Determining net Requirement, Time Phased Order Point.

Unit IV: Material management: 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.

Suggested Readings:

Arrow, K. J., Karlin, S., & Scarf, H. E. (1958). *Studies in the mathematical theory of inventory and production*. Stanford University Press.

Axsäter, S. (2015). *Inventory control*. Springer.

Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.

Muckstadt, J. A., & Sapra, A. (2010). *Principles of inventory management: when you are down to four, order more*. Springer-Verlag.

Naddor, E. (1966). *Inventory Systems*. Wiley

Ploss, G. W. (1985). *Production and inventory control-principle and techniques* (2nd ed.). Prentice Hall.

Porteus, E. L. (2002). *Foundations of stochastic inventory theory*. Stanford University Press.

Schwarz, L. B. (1981). *Multi-level production/inventory control systems: theory and practice*. North Holland.

Sherbrooke, C. C. (2004). *Optimal inventory modeling of systems: multi-echelon techniques* (2nd ed.). Springer.

Zipkin, H. P. (2000). *Foundations of inventory systems*. McGraw-Hill.

Teaching Plan:

Week 1-4: Overview of EOQ model and its extensions. 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.

Week 5-8: Multi-echelon inventory systems: 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.

Week 9-12: Inventory control in Supply-Chains. Material Requirement Planning (MRP): Approaches and benefits of MRP. Inputs to an MRP system. Dependent Demand, Bill of Material, Determining net Requirement, Time Phased Order Point.

Week 13-15: Material management: 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.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• A thorough understanding of classical inventory models and their extension • A set of quantitative tools for analysing the costs and optimal solutions for inventory policies in different environment	Group discussion, Class discussion on real world problems, Presentations, Case studies from industries and their solution approach	Weekly Assignment, Class test, Student Presentations, Solving different case studies with

II	• Knowledge of the approaches to multi-echelon inventory systems that have been proposed in the literature • A sampling of the more complex models that have been developed using classical models as a basis		the help of LINGO/ Excel Solver, End-term examination
III	• Inventory control in Supply-Chains • An understanding of Material Requirement Planning (MRP)		
IV	• Understand the fundamentals of material management		

Course - MOR401-403(iii): Queueing Networks

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

To acquaint students with the theory of queueing networks which are powerful and versatile tool for the performance evaluation and prediction of resource sharing systems such as computer, communication, traffic, manufacturing systems. To introduce techniques to solve various types of queuing networks analytically and numerically.

Course Learning Outcomes:

Students completing this course will be able to:

- Properly introduced to the networks of queues and its classification.
- Understanding of product form networks.
- Knowledge of various algorithms used to solve different types of networks, and to evaluate their measures of performance.
- Introduced to various application areas of queueing networks through case studies.

Contents:

Unit I: Departure process from M/M/-/- queue, Time reversibility, Reversible Markov chains, Burke's theorem.

Unit II: Introduction to queueing networks: classification and basic concepts, Open and closed queueing networks, Series queue (Tandem queue), Cyclic queues, Queue output, Single class networks: Traffic equations, Stability and its performance measures, Product-form networks, Global balance and local balance properties, Jacksons networks and Jacksons theorem for solving open networks, Gordon-Newell networks and Gordon-Newell theorem for solving closed networks, Derivation of performance measures for both open and closed networks, Mean-Value Analysis (MVA) algorithm for closed networks.

Unit III: Multi-Class networks and their solutions (BCMP Networks), Mixed queueing networks, Approximate analysis of open networks of GI/G/m queues using the Queueing Network Analysis (QNA) approach.

Unit IV: Blocking models in queueing networks, Series queues with blocking, Different numerical methods for their solutions, Non-Jackson networks.

Unit V: Applications of queueing networks in computer systems and communication systems, service industry, supply chain management.

Suggested Readings:

Balsomo, S., Vittoria De, N. P., & Onvural, R. (2001). *Analysis of queueing networks with blocking*. Kluwer Academic Publishers.

Bolch, G., Greiner, S., Meer, H. de, & Trivedi, K. S. (2006). *Queueing networks and markov chains: modeling and performance evaluation with computer science applications* (2nd ed.). New Jersey: Wiley-Interscience.

Chen, H., & Yao, David D. (2001). *Fundamentals of queueing networks-performance, asymptotics and optimization.* Springer-Verlag.

Kelly, F., & Yudovina, E. (2014). *Stochastic networks* (1st ed.). Cambridge University Press.

Kobayashi H., & Mark, B. L. (2008). *System modelling and analysis- foundations of system performance evaluation.* Prentice-Hall.

Perron, H. G. (1994). *Queueing networks with blocking*. Oxford University Press.

Robertazzi, T. G. (2000). *Computer networks and systems-queueing theory and performance evaluation* (3rd ed.). New York: Springer-Verlag.

Teaching Plan:

Week 1-2: Departure process from M/M/-/- queue, Time reversibility, Reversible Markov chains, Burke's theorem.

Week 3-5: Introduction to queueing networks: classification and basic concepts, Open and closed queueing networks, Series queue (Tandem queue), Cyclic queues, Queue output, Single class networks: Traffic equations, Stability and its performance measures, Product-form networks, Global balance and local balance properties

Week 6-9: Jacksons networks and Jacksons theorem for solving open networks, Gordon-Newell networks and Gordon-Newell theorem for solving closed networks, Derivation of performance measures for both open and closed networks, Mean-Value Analysis (MVA) algorithm for closed networks.

Week 10-12: Multi-Class networks and their solutions (BCMP Networks), Mixed queueing networks, Approximate analysis of open networks of GI/G/m queues using the Queueing Network Analysis (QNA) approach.

Week 13-15: Blocking models in queueing networks, Series queues with blocking, Different numerical methods for their solutions, Non-Jackson Networks. Applications of queueing networks in computer systems and communication systems, service industry, supply chain management.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• Understand the concept of time reversibility and reversible Markov chains. • Understand Burke's theorem and its connection with Markovian departure process, and its application in queueing networks.	Group discussions, Class discussions on real life problems, Presentations	Weekly assignments, Class tests, Student presentation, End-term examination
II	• Define a queueing network and understand various types of networks • Understand the difference between single class and multi class networks • Understand the concept of stability of networks, and the meaning of global and local balance in networks • Define various performance measures of a queueing network • Define a product-form network • To identify Jacksons networks and Gordon-Newell networks • Implement the Jacksons theorem and Gordon-Newell theorem to solve open and closed netwoks, and obtain the performance measures • Implement MVA alogorithm to solve closed networks		
III	• Solve multi-class (BCMP) networks • Define mixed queueing networks, and follow the QNA approach		

IV	• Understand the concept of blocking in a network • Solve simple networks with blocking • Have basic idea of non-Jackson network		
V	• Apply theory of queueing networks in various domains such as computer and communication systems, service industry, supply chain management		

Course - MOR401-403(iv): Quality Management

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:
To impart the knowledge of concepts related to quality management and how to tackle those issues and problems and to develop practical skills for continuous quality improvement.

Course Learning Outcomes:
Students completing this course will be able to:

- Explain the basic concepts related to quality management such as what is quality, need for quality management, evolution of quality management, product and service quality
- Identify major quality gurus and their contributions in the field of quality management and describe theoretically the various quality costs and concepts related to Total Quality Management
- Identify the various causes of variations in process capability and explain statistical process control and process control charts
- Explain theoretically the various statistical concepts like sampling plan, sampling distributions, OC curve, consumer's and producer's risk
- Describe the concept and role of six sigma along with theoretical workings of the implementation of six sigma using DMAIC and DMADV
- Explain the need and importance of FMEA and Poka-yoke
- Explain in detail the concepts related to Kaizen, benchmarking and QFD

Contents:
Unit I: Evolution of quality management, Concepts of product and service quality, Dimensions of quality, Major quality gurus: Deming, Ishikawa, Taguchi; Quality costs, Total quality management, Total quality management excellence model, Capability maturity model integration.

Unit II: Process and product quality, Causes of variations (assignable and unassignable), Statistical process control, Process control charts: variable control charts (*X*-bar and *R*, *X*-bar and *s*) and attribute control charts (*np* and *p*, *c* and *u*), Sampling, Sampling distribution, Acceptance sampling plan: single, double, multi-stage and sequential; Acceptable quality level, Average outgoing quality, Average outgoing quality limit, Operating characteristic curve, Consumer's risk, Producer's risk.

Unit III: Pareto chart, Cause and effect diagram, Check sheet, Histogram, Scatter diagram, Process control charts applications, Graphs: circle graph, bar graph and radar graph.

Affinity diagram, Relations diagram, Systematic or tree diagram, Matrix diagram, Matrix data analysis, Arrow diagram, Process decision program chart.

Unit IV: Variation, Causes of variations (natural and assignable), Statistical process control, Measurement system analysis, Process capability indices, Concept of six sigma, Implementation of six sigma: DMAIC, DMADV, Failure mode and effect analysis.

Unit V: Benchmarking for process/service improvement, Concepts of kaizen, Kaizen in practice, Kaizen versus innovation, Lean, 5S, Quality function deployment, Quality control circle, Poka-Yoke.

Suggested Readings:

Besterfield, D. H. (2004). *Quality control*. India: Pearson Education India.

Charantimath, P.M. (2011). *Total quality management*. India: Pearson Education India.

Evans, J. R., & Lindsay, W. M. (2002). *The management and control of quality (volume 1).* Cincinnati, OH: South-Western.

Montgomery, D. C. (2009). *Introduction to statistical quality control*. New York: John Wiley & Sons.

Gupta, S. C., & Kapoor, V. K. (2009). *Fundamentals of applied statistics*. India: Sultan Chand & Sons.

Teaching Plan:

Week 1: Evolution of quality management, Concepts of product and service quality, Dimensions of quality.

Week 2: Major quality gurus: Deming, Ishikawa, Taguchi.

Week 3: Quality costs, Total quality management, Total quality management excellence model, Capability maturity model integration.

Week 4-5: Process and product quality, Causes of variations (assignable and unassignable), Statistical process control, Process control charts: variable control charts (*X*-bar and *R*, *X*-bar and *s*) and attribute control charts (*np* and *p*, *c* and *u*).

Week 6: Sampling, Sampling distribution, Acceptance sampling plan: single, double, multi-stage and sequential.

Week 7: Acceptable quality level, Average outgoing quality, Average outgoing quality limit, Operating characteristic curve, Consumer's risk, Producer's risk.

Week 8: Pareto chart, Cause and effect diagram, Check sheet, Histogram, Scatter diagram.

Week 9: Application of process control charts: variable control charts (X-bar and R, X-bar and s) and attribute control charts (np and p, c and u).
Week 10: Affinity diagram, Relations diagram, Systematic or tree diagram, Matrix diagram, Matrix data analysis, Arrow diagram, Process decision program chart.
Week 11: Measurement system analysis, Process capability indices.
Week 12-13: Concept of six sigma, Implementation of six sigma: DMAIC, DMADV, Failure mode and effect analysis.
Week 14-15: Benchmarking for process/service improvement, Concepts of kaizen, Kaizen in practice, Kaizen versus innovation, Lean, 5S, Quality function deployment, Quality control circle, Poka-Yoke.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Explain the basic concepts related to quality management such as what is quality, need for quality management, evolution of quality management (ii) Explain the concepts of product and service quality (iii) Identify major quality gurus and their contributions in the field of quality management (iv) Describe theoretically the various quality costs (v) Explain theoretically the concepts related to Total Quality Management	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts (ii) Give extensive examples during lectures (iii) Give homework assignments (iv) Encourage the students to give short presentation (v) Encourage the students to participate in class discussion (vi) Encourage the students to apply concepts to solve real-world problems	• Hold class discussion and presentation • Homework assignments • Final exam • Group projects involving students to solve real-world problems • Hold both announced and unannounced quizzes
II	(i) Identify the various causes of variations in process capability (ii) Explain theoretically statistical process control and process control charts both variable and attribute (iii) Describe and apply different sampling distributions (iv) Explain theoretically the various statistical concepts like sampling plan, OC curve, consumer's and producer's risk		
III	(i) Demonstrate the application of various quality improvement tools		

	like, variable control charts, attribute control charts, cause and effect diagrams (ii) Explain various quality management tools like affinity diagram, matrix diagram, relationship diagram	(vii) Encourage the students to follow learning by doing approach (viii) Encourage the students to help fellow classmates	
IV	(i) Describe the concept and role of six sigma (ii) Describe the theoretical workings of the implementation of six sigma using DMAIC and DMADV (iii) Explain the need and importance of FMEA and Poka-yoke (iv) Describe the various statistical concepts related to measurement system analysis like precision, accuracy, bias, linearity		
V	(i) Explain in detail the concepts related to Kaizen and its implementation like 5S, QCC, lean (ii) Differentiate between Kaizen and innovation (iii) Describe the concept of benchmarking (iv) Demonstrate the implementation of QFD		

Course - MOR401-403(v): Multicriteria Decision Models

Marks:100 **Duration: 3 Hrs.**

Course Objectives:

To familiarize students with the concepts, tools and techniques of real-world decision making problems under multiple criteria in both discrete and continuous domains of alternatives.

Course Learning Outcomes:

Students completing this course will be able to:

- Explain the concepts of multiple criteria decision making and its applications in real-world problems and define the solution concepts, optimality conditions and duality for multi-objective programming problems using both convex and generalized convex functions

- Describe the theoretical workings of the solution methods for multi-objective programming problems and demonstrate their working by hand and solver
- Describe the theoretical workings of the solution methods for Bottleneck linear assignment problem and Vehicle routing problem and demonstrate their working by hand and solver
- Explain the concepts of multiple criteria decision making under discrete domain of alternatives and its applications in real-world problems and describe the theoretical workings of the solution methods including Scoring models, multi-attribute value and function approach and demonstrate their working by hand and solver
- Describe the theoretical workings of the CCR and BCC DEA models for performance evaluation using both graphical analysis and linear programming applications and demonstrate their working by hand and solver
- Describe the theoretical workings of the AHP model for ranking and selection using Eigen vector method and approximation methods and demonstrate their working by hand and solver
- Describe the theoretical workings of the TOPSIS method for ranking and selection and demonstrate their working by hand and solver

Contents:

Unit I: Multiobjective optimization: Pareto optimality, Trade-off, Proper pareto optimality, Optimality conditions, Lexicographic optimality, Solution methods, Duality theory.

Unit II: Bottleneck linear assignment problem, Vehicle routing problem, Scoring models, Multi attribute value and utility functions.

Unit III: Data envelopment analysis (DEA): Graphical analysis for efficient frontier, Charne's, Cooper and Rhodes (CCR) model, Banker, Charne's and Cooper (BCC) model, Analytic hierarchy process (AHP): Ranking and weighting information using eigen vector method and approximation methods, Ranking and weighting information using Technique for order of preference by similarity to ideal solution (TOPSIS) method.

Suggested Readings:

Ballestero, E., & Romero, C. (1998). *Multiple criteria decision making and its application to economic problems*. New York: Springer.

Cooper, W. W., Seiford, L. M., & Tone, K. (2007). *Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software*. New York: Springer.

Ehrgott, M. (2005). *Multicriteria optimization* (2nded.). New York: Springer.

Miettinen, K. (1998). *Nonlinear multiobiective optimization*, New York: Springer.

Steuer, R. E. (1986). *Multiple criteria optimization-theory, computation, and application.* Wiley Series in Probability and Mathematical Statistics-Applied, Wiley.

Taha, H. A. (2007). *Operations research-an introduction* (8th ed.). New Delhi: Pearson Prentice Hall (Indian print).

Tzeng, G.-H., & Huang, J.-J. (2011). *Multiple attribute decision making: methods and applications.* Florida: CRC Press.

Teaching Plan:

Week 1-4: Introduction to multiple criteria decision making and its applications in real-world problems using both continuous and discrete domains of alternatives, Pareto optimality, Trade-off and proper pareto optimality, Karush-Kuhn-Tucker optimality conditions, Lexicographic optimality, Wolfe and Mond-Weir duals.

Week 5-7: Solutions methods including Weighted sums method, Epsilon constraint method, Method of global criterion, Compromise programming, Goal programming and Interactive approach, Necessary and sufficient conditions for pareto optimality and relationship among solution obtained through various methods.

Week 8-10: Mathematical formulation and solution of Bottleneck linear assignment problem, Mathematical formulation and solution of Vehicle routing problem, Introduction to Scoring models and Multi attribute value and utility functions.

Week 11-12: Introduction to DEA, Graphical analysis for efficient frontier, Linear programming applications through CCR and BCC models for performance evaluation.

Week 13-15: Introduction to AHP model, Ranking and selection of alternatives through AHP model using eigen vector method and approximation methods, Ranking and selection of alternatives through TOPSIS method.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Explain the concepts of multiple criteria decision making and its applications in real-world problems (ii) Define the solution concepts and optimality conditions for multi-objective programming problems using both convex and generalized convex functions (iii) Describe the theoretical workings of the solution methods for multiobjective programming problems and demonstrate their working by hand and	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts (ii) Give extensive examples during lectures. (iii) Give homework assignments using hand calculations and solver (iv) Encourage students to participate in class discussion (v) Encourage students to give short presentation (vi) Encourage students to apply concepts to solve real-world problems using solver	• Hold class discussion and presentations • Homework assignments • Final exam • Group activities involving students to solve real-world problems using solver • Hold both announced and unannounced quizzes

	solver (v) Define the dual problems, namely Wolfe dual and Mond-Weir dual for multiobjective programming problems and establish duality relationships between primal-dual problems		
II	(i) Describe the theoretical workings of the solution methods for Bottleneck linear assignment problem and Vehicle routing problem and demonstrate their working by hand and solver (ii) Explain the concepts of multiple criteria decision making under discrete domain of alternatives and its applications in real-world problems (iii) Describe the theoretical workings of the solution methods including Scoring models, multi-attribute value and function approach and demonstrate their working by hand and solver		
III	(i) Describe the theoretical workings of the CCR and BCC DEA models for performance evaluation using both graphical analysis and linear programming applications and demonstrate their working by hand and solver (ii) Describe the theoretical workings of the		

	AHP model for ranking and selection using Eigen vector method and approximation methods and demonstrate their working by hand and solver (iii) Describe the theoretical workings of the TOPSIS method for ranking and selection and demonstrate their working by hand and solver		

Course - MOR401-403(vi): Data Warehousing and Data Mining

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

This course will introduce the concepts, techniques, design and applications of data warehousing and data mining. The course is expected to enable students to understand and implement classical algorithms in data mining and data warehousing. Students will learn how to analyse the data, identify the problems, and choose the relevant algorithms to apply.

Course Learning Outcomes:

Students completing this course will be able to:

- Provide the student with an understanding of the concepts of data warehousing and data mining.
- Study the dimensional modeling technique for designing a data warehouse.
- Study data warehouse architectures, OLAP and the project planning aspects in building a data warehouse.
- Explain the knowledge discovery process. Describe the data mining tasks and study their well-known techniques.
- Enable students to understand and implement classical algorithms in data mining and data warehousing. Assess the strengths and weaknesses of the algorithms, identify the application area of algorithms, and apply them.
- Test real data sets using popular open source data mining tools such as WEKA (Waikato Environment for Knowledge Analysis).

Contents:

Unit I: Data Warehousing: 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: Data Mining: 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, Dimensionality Reduction: Principal Component Analysis (PCA), Data Discretization, Normalization.

Association Rule Mining: Market Basket Analysis, Frequent Itemsets, Closed Item sets, and Association Rules; Efficient and Scalable Frequent Itemset Mining Methods: The Apriori algorithm, Improving the Efficiency of Apriori algorithm, Frequent Pattern (FP) Growth algorithm; Mining Frequent itemsets using vertical data formats; Mining closed and maximal patterns; From Association Mining to Correlation Analysis, Pattern Evaluation Measures; Introduction to Constraint-Based Association Mining.

Unit III: Classification and Prediction: Issues Regarding Classification and Prediction, Classification by Decision Tree Induction, Bayesian Classification, Rule Based Classification, Classification by Back propagation, Support Vector Machines. Prediction: Structure of regression models; linear and non-linear regression. Model Evaluation & Selection**:** Accuracy and Error measures, evaluating the Accuracy of a Classifier or Predictor.

Unit IV: Cluster Analysis: Types of Data in Cluster Analysis. Clustering Methods: Partitioning Methods, Hierarchical methods, Density-Based Methods, Grid-Based Methods, Model-Based Clustering Methods. Clustering High-Dimensional Data, Cluster Validation, Outlier Analysis**.** Introduction to Mining Object, Spatial, Multimedia, Text and Web Data

Suggested Readings:

Adriaans, P., & Zantinge, D. (1996). *Data mining*. Addison Wesley.

Berry, M. J. A., & Linoff, G (2011). *Data mining techniques: for marketing, sales, and customer relationship management* (3rd ed.). John Wiley.

Berson, J., & Stephen S. (2007). *Data warehousing, data mining and OLAP* (10th reprint). McGraw Hill.

Fayaad, U. M., Piatetsky-Shapiro, G., Smyth, P., & Uthurusarny, R. (1996). *Advances in knowledge discovery and data mining.* MIT Press.

Gupta, G. K. (2014). *Introduction to data mining with case studies* (3rd ed.). PHI Learning.

Jiawei, H., Micheline K., & Jian P. (2011). *Data mining: concepts and techniques* (3rd ed.). Morgan Kaufmann.

Larose, D. T., & Larose, C.D. (2015). *Data mining and predictive analytics* (2nd ed.). Wiley-Blackwell.

Pang-ding, T., Steinbach, M., & Kumar, V. (2005). *Introduction to data mining*. Addison Wesley.

Teaching Plan:

Week 1-2: 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..

Week 3-4: Data Mining: 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, Dimensionality Reduction, Data Discretization, Normalization.

Week 5-7: Association Rule Mining: Market Basket Analysis, Frequent Itemsets, closed Itemsets, and Association Rules; Efficient and Scalable Frequent Item set Mining Methods: The Apriori algorithm, Improving the Efficiency of Apriori algorithm, Frequent Pattern (FP) Growth algorithm; Mining Frequent itemsets using vertical data formats; Mining closed and maximal patterns; From Association Mining to Correlation Analysis, Pattern Evaluation Measures; Introduction to Constraint-Based Association Mining.

Week 8-11: Classification and Prediction: Issues Regarding Classification and Prediction, Classification by Decision Tree Induction, Bayesian Classification, Rule Based Classification, Classification by Back propagation, Support Vector Machines. Prediction: Structure of regression models; linear and non-linear regression. Model Evaluation & Selection: Accuracy and Error measures, evaluating the Accuracy of a Classifier or Predictor.

Week 12-13: Cluster Analysis: Types of Data in Cluster Analysis. Clustering Methods: Partitioning Methods, Hierarchical methods, Density-Based Methods, Grid-Based Methods, Model-Based Clustering Methods. Clustering High-Dimensional Data, Cluster validation, Outlier Analysis.

Week 14-15: Introduction to Mining Object, Spatial, Multimedia, Text and Web Data.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	• Provide the student with an understanding of the concepts of data warehousing and data mining. • Study the dimensional modeling technique for designing a data warehouse. • Study data warehouse architectures, OLAP and the project planning aspects in building a data warehouse	Group discussion, Class discussion on real world problems, Presentations, Case studies	Weekly assignment, Class test, Student Presentations, Solving different case studies with the help of WEKA and other open source softwares

II	• Explain the knowledge discovery process • Describe the data mining tasks and study their well-known techniques • Learn exploratory data mining techniques • Learn about Dimensionality Reduction, Data Discretization, Normalization • Study Association Rule Mining		
III	• Understand and implement classical algorithms for classification and prediction • Learn about Model Evaluation & Selection procedure. • Understand the Accuracy and Error measures; evaluate the Accuracy of a Classifier or Predictor		
IV	• Understand and implement classical algorithms for clustering analysis • Learn about Cluster validation, Outlier Analysis • Understand Mining Object, Spatial, Multimedia, Text and Web Data		

Course - MOR401-403(vii): Decision Theory

Marks: 100 **Duration: 3 Hrs.**

Course Objectives:

To teach how optimal choice can be made amongst alternative courses of actions (decisions) with uncertain consequences using non-probabilistic, probabilistic and utility theory approaches, and also how to construct and analyze decision support systems using decision trees and Bayesian decision networks.

Course Learning Outcomes:

Students completing this course will be able to:

- Analyze problems when the decision maker has no knowledge about various states of nature; not even sufficient to permit the assignment of probabilities to them.

- Learn about Bayesian Decision Theory; decision making without sampling with Discrete Prior ,Beta Prior of I-kind, and Normal prior; decision making with data using Beta prior of I-kind and Binomial sampling, Beta prior of I-kind and Geometric sampling, Normal prior and normal sampling.
- Learn about decision making using utility theory approach which takes into account subjective preference measure of the decision maker to an outcome or payoff of an action.
- Learn modeling of risk attitudes that change as circumstances and current fortunes change; of use in insurance decision making.
- Decision making with first, second and third degree stochastic dominance decision rules that enable partial ordering amongst competing alternatives; which are helpful in investment decision making, agriculture, medicine, etc..
- Learn about sequential decision making under uncertainty using Markov Decision Process model that produces a sequence of Markov chains with rewards.
- Obtain optimal decisions using graphical approach- decision trees and Bayesian Decision network.

Contents:

Unit I: Prescriptive decision analysis; history of decision analysis; Basic elements of decision analysis; Modeling of Decision Problems; Non-probabilistic criteria for decision making under uncertainty: Preference Orderings, The Maximin Rule, The Minimax Regret Rule, The Optimism-Pessimism Rule, The Principle of Insufficient Reasoning.

Unit II: Decision Analysis under Risk: Probabilistic Approach- Bayesian Decision Theory: Prior, Posterior, and pre-posterior analysis; Decision Analysis without Sampling; Decision Analysis with Sampling; Utility Theory Approach - St. Petersburg Paradox, Expected Utility Principle, Construction of Utility Functions, multi-attribute utility theory, Risk Attitudes, Utility theory and insurance; Stochastic Dominance Decision Rules.

Unit III: Sequential Decision Making under uncertainty: Markov Decision Processes (MDPs) -An introduction, Bandit Problems, Decision-Theoretic Bandit process, MDPs and reinforcement learning, Finite Horizon MDPs, Infinite Horizon MDPs; Partially observable MDPs.

Unit IV: Decision Trees and Bayesian Decision Networks.

Suggested Readings:

Fenton, N., & Neil, M. (2013). *Risk assessment and decision analysis with bayesian networks*. New York: CRC Press, Taylor and Francis Group.

Jensen, F. V., & Nielson, T. D. (2007). *Bayesian networks and decision graphs* (2nd ed.). New York: Springer Science.

Jones, J. M (1977). *Introduction to decision theory, irwin series in quantitative analysis for business* (1st ed.). New York: Irwin (Richard D.) Inc.

Levy, H. (2006). Stochastic dominance – investment decision making under uncertainty (2nd ed.). New York: Springer Science.

Parmigiani, G., & Inoue, L. (2009). *Decision theory-principles and approaches*. UK: John Wiley & Sons Ltd.

Sheskin, T. J. (2010). *Markov chains and decision processes for engineers and managers*. New York: CRC Press, Taylor and Francis Group.

Smith, J. Q. (2010). *Bayesian decision analysis-principles and practice*. UK: Cambridge University Press.

Kaas, R., Goovarts, M., Dhaene, J., & Denuit, M. (2001). *Modern actuarial risk theory*. Netherlands: Kluwer Academic Publishers.

Teaching Plan:

Week 1: Prescriptive decision analysis; history of decision analysis; Basic elements of decision analysis, Modeling of Decision Problems.

Week 2: Nonprobabilistic criteria for decision making under uncertainty: Preference Orderings, The Maximin Rule, The Minimax Regret Rule, The Optimism-Pessimism Rule, The Principle of Insufficient Reasoning.

Week 3: Bayesian Decision Theory: Prior, Posterior and pre-posterior analysis,.

Week 4: Decision Analysis without Sampling - Discrete Prior Distribution, Beta Prior of I-kind, Normal prior.

Week 5-6: Decision Analysis with Sampling - Beta prior of I-kind with Binomial, Beta prior of I-kind with Geometric sampling, Normal prior with normal sampling.

Week 7-8: St. Petersburg Paradox, Expected Utility Property, Construction of Utility Functions, Risk Attitudes, Multiattribute utility theory ,Utility theory and Insurance.

Week 9-10: Stochastic Dominance Decision Rules - First degree stochastic dominance(FSD), Second Degree stochastic dominance(SSD), Third Degree Stochastic Dominance(TSD), Algorithms for stochastic dominance, Applications of stochastic dominance rules

Week 11: Markov Decision Processes (MDPs) :An introduction, Bandit Problems, Decision-Theoretic Bandit process, MDPs and reinforcement learning.

Week 12-13: Finite Horizon MDPs; Infinite Horizon MDPs; Partially observable MDPs.

Week 14- 15: Decision Trees and Bayesian Decision Networks.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	Make decisions under uncertainty.	Lectures and Class Presentations.	Class Presentations, Written Assignments and class tests including final semester examination.
II	Carry out Decision Analysis under Risk using Probabilistic Approach and utility theory approach, and also learn about Stochastic Dominance Rules that enable partial ordering among competing alternatives.		

III	Analyze Sequential Decision problems using Markov Decision Process models.		
IV	Obtaining optimal decisions using decision trees and Bayesian Decision Networks.		

Course - MOR401-403 (viii): Dynamic Optimization

Marks:100 **Duration: 3 Hrs.**

Course Objectives:

To familiarize students with the concepts, tools and techniques of dynamic optimization, stochastic dynamic programming, calculus of variation and control theory for dealing with wide range of real-world decision making problems under uncertainty and involving time variable.

Course Learning Outcomes:

Students completing this course will be able to:

- Explain the concepts of dynamic optimization and its application in real-world problems and define the solution concepts and optimality conditions
- Set up and solve dynamic optimization problems both analytically and numerically and demonstrate their working by hand and solver
- Describe the formulation of simple control models and demonstrate their working by hand and solver
- Describe the maximum principle as a necessary condition for optimal control problem and its derivation using dynamic programming.
- Describe the conditions under which maximum principle conditions are also sufficient
- Describe the applications of optimal control theory in marketing, inventory systems, financial investment
- Describe the Itô stochastic differential equations and their use in stochastic optimal control

Contents:

Unit I: Non-sequential and sequential discrete optimization, Existence and uniqueness theorem, Dimensionality reduction method, Stochastic dynamic programming.

Unit II: Introduction to calculus of variations, Fundamental problems, Weak and strong extrema, Necessary and sufficient conditions.

Unit III: Fundamentals of optimal control, Mathematical models of continuous and discrete time optimal control problems, Maximum principle, Necessary and sufficient conditions for optimality, Optimal control problems applied in marketing, inventory systems and financial investment, Stochastic optimal control.

Suggested Readings:

Chiang, A. C. (1999). *Elements of dynamic optimization.* Illinois: Waveland Press Inc.

Hadley, G. (1964). *Nonlinear and dynamic programming*. Boston: Addison-Wesley.

Kaufmann, A., & Croun, R. (1967). *Dynamic programming*. New York: Academic Press.

Kirk, D. (1970). *Optimal control theory- an introduction.* New Jersey: Prentice Hall.

Maccluer, C. R. (2004). *Calculus of variations-mechanics, control theory, and other Applications.* New Jersey: Prentice Hall.

Pontryagin, L. S. (1986). *Mathematical theory of optimal processes, volume four.* Montreux, CH: Gordonand Breach Science Publishers S. A.

Seierstad, A., & Sydsaeter, K. (1987). *Optimal control theory with economic applications*. North Holland: Elsevier.

Sethi, S. P., & Thompson, G. L. (2006).*Optimal control theory-applications to management science and economics*. New York: Springer.

Teaching Plan:

Week 1-4: Introduction to non-sequential and sequential discrete optimization, Existence and uniqueness theorem, Dimensionality reduction method.

Week 5-8: Stochastic dynamic programming, Introduction to calculus of variations, Fundamental problems, Weak and strong extrema, Necessary and sufficient conditions.

Week 9-12: Fundamentals of optimal control, Mathematical models of continuous and discrete time optimal control problems, Maximum principle, Necessary and sufficient conditions for optimality, Stochastic optimal control.

Week 13-15: Optimal control problems applied in marketing, inventory systems and financial investment.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Explain the concepts of dynamic optimization (ii) Describe the applications in real-world problems (iii) Define the solution concepts and optimality conditions	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts (ii) Give extensive examples during lectures. (iii) Give homework assignments using hand calculations and solver (iv) Encourage students to participate in class discussion	• Hold class discussion and presentations • Homework Assignments • Final exam • Group activities involving students to solve real-world problems using solver • Hold both
II	(i) Set up and solve dynamic optimization problems both analytically and numerically and demonstrate their working		

	by hand and solver (ii) Describe the formulation of simple control models and demonstrate their working by hand and solver	(v) Encourage students to give short presentation (vi) Encourage students to apply concepts to solve real-world problems using solver	announced and unannounced quizzes
III	(i) Describe the maximum principle as a necessary condition for optimal control problem and its derivation using dynamic programming (ii) Describe the conditions under which maximum principle conditions are also sufficient (iii) Describe the applications of optimal control theory in marketing, inventory systems, financial investment (iv) Describe the Itô stochastic differential equations and their use in stochastic optimal control		

Course - MOR401-403(ix): Portfolio Management

Marks:100 **Duration: 3 Hrs.**

Course Objectives:

To impart the knowledge of concepts and approaches to portfolio management to tackle the issues and problems of investment management in a global market and develop practical skills in investment management to understand of how the theories relate to practice.

Course Learning Outcomes:

Students completing this course will be able to:

- Explain the theoretical terminologies essential for portfolio management such as types of assets, asset return, risk, short selling, liquidity and market impact, hedging principle

- Describe the theoretical workings of the two asset and multi asset portfolio optimization and demonstrate how to make optimal capital allocation and portfolio choice decisions on real-data set by hand and solver when investors have mean-variance preferences
- Discriminate between the different sources of risk and demonstrate the concept of diversification: how and why putting risky assets together in a portfolio eliminates risk that yields a portfolio with less risk than its components
- Describe the theoretical workings of the mean absolute model, mean semi-absolute deviation model, mean value at risk model, mean conditional value at risk model, allocation based upon marginal contributions and demonstrate their working by hand and solver
- Describe the theoretical workings of the capital asset pricing model and factor models and demonstrate their working by hand and solver
- Demonstrate measures to evaluate a portfolio's performance relative to a benchmark on a real-data set

Contents:

Unit I: Introduction to portfolio management: Types of assets, Risk/return concepts and measurements, Portfolio of assets, Portfolio return and risk, Diversification, Short selling, Mean-variance efficient frontier, Alternate risk measures, Liquidity and market impact, Hedging principle.

Unit II: Portfolio optimization: Markowitz portfolio selection model, Two fund theorem, Portfolio selection models using alternate risk measures-Mean absolute deviation model, Mean semi-absolute deviation model, Mean value at risk model, Mean conditional value at risk model, Portfolio selection based upon marginal contributions to risk and implied returns, Performance evaluation measures-Jenson ratio, Sharpe ratio, Treynor ratio.

Unit III: Capital market theory, Capital assets pricing model, One fund theorem, Arbitrage pricing theory, Index models.

Suggested Readings:

Bartholomew-Biggs, M. (2005). *Nonlinear optimization with financial applications*. New York: Springer.

Grinold, R. C., & Kahn, R. N. (1999). *Active portfolio management-a quantitative approach for producing superior returns and controlling risk*. New York: McGraw Hill.

Gupta, P., Mehlawat, M. K., Inuiguchi, M., & Chandra, S. (2014). *Fuzzy portfolio optimization: advances in hybrid multi-criteria methodologies*. Berlin: Springer.

Lhabitant, F. S. (2007). *Handbook of hedge funds*. New Jersey: Wiley.

Luenberger, D. G. (2010). *Investment science.* New York: Oxford University Press Inc. (Indian Print).

Markowitz, H. M. (2000). *Mean-variance analysis in portfolio choice and capital markets*. New Jersey: Wiley.

Marrison, C. (2002). *The fundamentals of risk measurement*. New York: McGraw Hill.

Prigent, J. L. (2007). *Portfolio optimization and performance analysis*. London: CRC Press.

Reilly, F. K., & Brown, K. C. (2009). *Investment analysis and portfolio management* (10th ed.). South-Western: Cengage Learning.

Roman, S. (2004). *Introduction to the mathematics of finance: from risk management to options pricing*. Berlin: Springer.

Sharpe, W. F. (1999). *Portfolio theory and capital markets*. New York: McGraw Hill.

Teaching Plan:

Week 1-4: Types of assets, Risk/return concepts and measurements, Portfolio return and risk, Diversification, Short selling, Mean-variance efficient frontier, Alternate risk measures, Hedging principle, Liquidity and market impact.

Week 5-9: Markowitz portfolio selection model. Portfolio selection models using alternate risk measures- absolute deviation, semi-absolute deviation, value at risk, conditional value at risk.

Week 10-11: Portfolio selection based upon marginal contributions to risk and implied returns, Performance evaluation measures: Jenson ratio, Sharpe ratio, Treynor ratio.

Week 12-13: Capital market theory, Capital assets pricing model.

Week 14-15: Arbitrage pricing theory, Index models.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
I	(i) Explain the theoretical terminologies essential for portfolio management such as asset return, risk, short selling (ii) Describe the theoretical workings of the two asset and multi asset portfolio optimization and demonstrate how to make optimal capital allocation and portfolio choice decisions when investors have mean-variance preferences on real-data set by hand and solver (iii) Demonstrate theoretically and on real-data set how to eliminate risk with and without short selling (iv) Discriminate between the different sources of risk and demonstrate the concept of diversification: how and why	(i) While introducing each topic some examples will be laid out and discussed with the students encouraging them to discover the relevant concepts (ii) Give extensive examples during lectures. (iii) Give homework assignments (iv) Encourage students to participate in class discussion (v) Encourage students to give short presentation (vi) Encourage students to apply	• Hold Class discussion and presentations • Homework assignments • Final exam • Group projects involving students to solve real-world investment problems using solver • Hold both announced and unannounced quizzes

	putting risky assets together in a portfolio eliminates risk that yields a portfolio with less risk than its components	concepts to solve real-world problems using solver (vi) Encourage students to follow learning by doing approach (vii) Encourage students to help fellow classmates	
II	(i) Describe the theoretical workings of the mean absolute model and demonstrate it working by hand and solver (ii) Describe the theoretical workings of the mean semi-absolute deviation model and demonstrate it working by hand and solver (iii) Describe the theoretical workings of the mean value at risk model, mean conditional value at risk model and demonstrate their working by hand and solver (iv) Demonstrate asset allocation based upon marginal contributions to risk and implied returns (v) Demonstrate measures to evaluate a portfolio's performance relative to a benchmark on a real data set		
III	(i) Describe the theoretical workings of the capital asset pricing model and demonstrate its working by hand (ii) Describe the theoretical workings of the factor models and demonstrate their working by hand		

Course - MOR401-403(x): Stochastic Processes

Marks: 100 **Duration: 3 Hrs.**

.**Course Objectives:**

To acquaint students with the basic concepts of the theory of stochastic processes. To introduce the most important types of stochastic processes and their properties. To introduce stochastic calculus and its applications to finance and economics.

Course Learning Outcomes:

Students completing this course will be able to:

- Elucidate the power of stochastic processes and their range of applications.
- State the defining properties of various stochastic process models.
- Demonstrate essential stochastic modeling tools.
- Identify appropriate stochastic process model(s) for a given research or applied problem.
- Formulate and solve problems which involve setting up stochastic models.
- Demonstrate the ability to apply the theory developed in the course to real world problems of an appropriate level of difficulty.

Contents:

Unit I: Stochastic processes: Definition, classification and properties, discrete time Markov chains, Poisson process, continuous time Markov chains, Absorbing Markov chains, Phase type distribution.

Unit II: Automated generation: Petri nets, Generalized Stochastic Petri nets, Stochastic reward nets, GSPN/SRN analysis, Stochastic Petri net extensions.

Unit III: Generalized Markov models: Basic concepts, Cumulative processes, Semi-Markov processes: Long-term analysis, Markov regenerative processes: Long-term analysis.

Unit IV: Martingale, Random walk, White noise, Gaussian process, Brownian motion (Wiener process), Branching processes, Hidden Markov models.

Unit V: Stochastic calculus: Stochastic differential equations, Ito integral, Ito formula and its variants, Applications to finance.

Suggested Readings:

Blanco, L., Arunachalam, V., & Dharmaraja S. (2016). *Introduction to probability and stochastic processes with applications.* Castaneda, Wiley, Asian Edition.

Kulkarni, V. G. (2011). *Modeling and analysis of stochastic systems* (2nd ed.), CRC Press.

Medhi, J. (2009). *Stochastic processes* (3rd ed.). New Age International Publishers.

Mikosch, T. (1998). *Elementary stochastic calculus with finance in view* (Advanced Series on Statistical Science & Applied Probability, volume 6). World Scientific.

Pinsky, M. A., & Karlin, S. (2011). *An introduction to stochastic modelling*. Elsevier.

Ross, S. M. (1995). *Stochastic processes* (2nd ed.), John Wiley.

Shreve, S. E. (2004). *Stochastic calculus for finance (volume I & II).* Springer.

Teaching Plan:

Week 1-4: Stochastic processes: Definition, classification and properties, discrete time Markov chains, Poisson process, continuous time Markov chains, Absorbing Markov chains, Phase type distribution.

Week 5-6: Automated generation: Petri nets, Generalized Stochastic Petri nets, Stochastic reward nets, GSPN/SRN analysis, Stochastic Petri net extensions.

Week 7-9: Generalized Markov models: Basic concepts, Cumulative processes, Semi-Markov processes: Long-term analysis, Markov regenerative processes: Long-term analysis.
Week 10-12: Martingale, Random walk, White noise, Gaussian process, Brownian motion (Wienerprocess), Branching processes, Hidden Markov models.
Week 13-15: Stochastic calculus: Stochastic differential equations, Ito integral, Ito formula and its variants, Applications in finance.

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course learning outcomes	Teaching and Learning Activity	Assessment Tasks
I	• Define a stochastic process and its characteristics. • Understand the complete theory of Markov chains and Markov processes. • Understand absorbing Markov chains and its theory. • Define phase type distribution and its special cases.	Group discussions, Class discussions on real life problems, Presentations	Weekly Assignments, Class Tests, Student presentation, End-term examination
II	• Understand and implement the stochastic Petri net modeling technique.		
III	• Understand and analyze various types of generalized Markov models in steady state.		
IV	• Define and understand the theory of various important stochastic processes mentioned in this unit.		
V	• Understand the theory of stochastic calculus, and its applications to finance.		

Course - MOR404-405: Project Work

Marks: 200

Course Objectives:

Provide real-world exposure of business decision problems. Each student has to work on a real-world business problem and has to understand, model and analyze the problem and also needs to provide its solution based on the knowledge acquired through various Operational Research (OR) tools taught in the curriculum.

Course Learning Outcomes:

Students completing this course will be able to:

- Understand and analyze the real-world business problems.
- Demonstrate essential OR modeling tools to solve the problem.
- Demonstrate the solution process using specialized OR softwares.
- Understand the policy implementation of the real-world decision.
- Understand how to present and compile a business project report.