MEASI Institute of Management

SUPPLY CHAIN ANALYTICS-534EDH

VISION & MISSION STATEMENT

Vision: To be an oasis of knowledge to the seeker, to nurture one's creativity and research acumen, and to instill a unique blend of leadership, innovative spirit, and empathy in response to the ever-evolving business ecosystem.

Mission:

- Provide a pedagogy that blends academic rigor and experiential learning.
- Inculcate an entrepreneurial mindset through curated activities.
- Establish a conducive environment for research.
- Foster a culture of innovation and collaboration to progress in a dynamic business landscape.
- Promote humanistic values to produce socially responsible leaders.

Program Educational Objectives (PEOs)

PEO 1 – Employability:

To develop students with industry-specific knowledge & skills to meet the industry requirements, and also join a public sector undertaking through competitive examinations.

PEO 2 – Entrepreneur:

To create effective business service owners with a growth mindset by enhancing their critical thinking, problem-solving, and decision-making skills

PEO3 – Research and Development:

To instil and grow a mindset that focuses efforts towards inculcating and encouraging the students in the field of research and development

PEO 4 – Contribution to Business World

To produce ethical and innovative business professionals to enhance the growth of the business world

PEO 5 – Contribution to the Society:

To work and contribute towards the holistic development of society by producing competent MBA professionals

Program Outcomes

PO1:Problem Solving Skill

Application of tools & techniques relevant to management theories and practices in analysing & solving business problems

PO2: Decision-Making Skill

Fostering analytical and critical thinking abilities for data-based decision making

PO3: Ethical Value

Ability to develop value-based leadership attributes

PO4: Communication Skill

Ability to understand, analyse, and effectively communicate global, economic, legal, and ethical aspects of business

PO5: Individual and Team Leadership Skill

Ability to be self-motivated in leading & driving a team towards the achievement of organizational goals and contributing effectively to establish industrial harmony

PO6: Employability Skill

Foster and enhance employability skills through relevant industry subject knowledge

PO7: Entrepreneurial Skill

Equipped with skills and competencies to become a global entrepreneur

PO8: Contribution to Society

Strive towards becoming a global influencer and motivating future generations towards building a legacy that contributes to the overall growth of humankind

SYLLABUS

Unit-1 Introduction: Introduction to analytics – descriptive, predictive, and prescriptive analytics, Data Driven Supply Chains – Basics, transforming supply chains, Barriers to implementation, Road Map.

Unit-2 Warehousing Decisions: Mathematical Programming Models - P-Median Methods - Guided LP Approach - Balmer – Wolfe Method, Greedy Drop Heuristics, Dynamic Location Models, Space Determination and Layout Methods.

Unit-3 Inventory Management: Inventory aggregation Models, Dynamic Lot sizing Methods, Multi-Echelon Inventory models, Aggregate Inventory system and LIMIT, Risk Analysis in Supply Chain - Measuring transit risks, supply risks, delivering risks, Risk pooling strategies.

Unit-4 Transportation Network Models: Notion of Graphs, Minimal Spanning Tree, Shortest Path Algorithms, Maximal Flow Problems, Multistage Transshipment and Transportation Problems, Set covering and Set Partitioning Problems, Traveling Salesman Algorithms, Advanced Vehicle Routing Problem Heuristics, Scheduling Algorithms-Deficit function Approach and Linking Algorithms

Unit-5 MCDM Models: Analytic Hierarchy Process (AHP), Data Envelopment Analysis (DEA), Fuzzy Logic and Techniques, the analytical network process (ANP), TOPSIS-Application in SCM.

Unit-1

1. Introduction to Analytics

- Analytics refers to the systematic computational analysis of data to discover meaningful patterns, insights, and trends that aid decision-making.
- In the context of business and supply chains, analytics helps organizations enhance efficiency, accuracy, and responsiveness.

1.1 Meaning

Analytics involves using data, statistical analysis, and quantitative models to make informed decisions. It transforms raw data into actionable insights.

1.2 Importance of Analytics

- Enables data-driven decision making.
- Enhances operational efficiency.
- Improves forecast accuracy and customer satisfaction.
- Reduces costs and risks.
- Supports strategic planning and competitive advantage.

2. Types of Analytics

Analytics can be broadly classified into three major categories:

2.1 Descriptive Analytics

Objective: To understand what has happened in the past.

Description:

Descriptive analytics summarizes historical data to identify trends and patterns.

It provides insights into past performance through reports, dashboards, and data visualization.

Techniques Used:

- Data aggregation
- Data mining
- Reporting and visualization tools

Examples in Supply Chain:

1. Monthly sales reports
2. Inventory turnover ratios
3. Supplier performance metrics
4. On-time delivery rates

Tools: Tableau, Power BI, Excel, QlikView

2.2 Predictive Analytics

Objective: To understand what is likely to happen in the future.

Description:

Predictive analytics uses historical data, statistical models, and machine learning to forecast future outcomes.

It identifies potential risks and opportunities.

Techniques Used:

- Regression analysis
- Time series forecasting
- Classification and clustering models
- Machine learning algorithms

Examples in Supply Chain:

1. Demand forecasting
2. Predicting supplier delays
3. Anticipating stock-outs or disruptions

Tools: Python, R, SAS, IBM SPSS, RapidMiner

2.3 Prescriptive Analytics

Objective: To determine what should be done for the best possible outcome.

Description:

Prescriptive analytics uses optimization and simulation techniques to recommend actions.

It suggests decisions that minimize cost, maximize profit, or achieve other objectives.

Techniques Used:

- Linear and non-linear optimization
- Simulation models
- Decision analysis
- Scenario planning

Examples in Supply Chain:

1. Optimal production scheduling
2. Route optimization for logistics
3. Inventory replenishment strategies

Tools: IBM CPLEX, Gurobi, LINGO, AnyLogic, Arena Simulation

Aspect	**Descriptive Analytics**	**Predictive Analytics**	**Prescriptive Analytics**
Focus	Past	Future	Decision/Action
Question Answered	What happened?	What could happen?	What should we do?
Techniques	Reporting, Visualization	Forecasting, ML Models	Optimization, Simulation
Outcome	Insight	Prediction	Recommendation

4. Data-Driven Supply Chains

4.1 Meaning

A Data-Driven Supply Chain (DDSC) uses real-time data, analytics, and digital technologies to plan, manage, and optimize all supply chain activities — from procurement to delivery.

4.2 Characteristics

- Real-time visibility
- Predictive demand and supply planning
- Data integration across stakeholders
- Automated decision-making
- Enhanced agility and responsiveness

4.3 Importance of Data-Driven Supply Chains

Reduces uncertainty and improves forecasting accuracy.

Enables proactive risk management.

Optimizes resource utilization.

Enhances customer experience through responsiveness.

Supports sustainability by reducing waste and inefficiencies.

5. Basics of Data-Driven Supply Chains

5.1 Data Sources

Internal data: Sales, production, inventory, logistics.

External data: Market trends, customer preferences, weather, supplier data, geopolitical data.

5.2 Technologies Enabling DDSC

- Internet of Things (IoT)
- Artificial Intelligence (AI) and Machine Learning (ML)
- Cloud Computing
- Big Data Analytics
- Blockchain for transparency
- Advanced Planning and Scheduling (APS) tools

5.3 Key Functional Areas

Procurement: Supplier evaluation, price prediction.

Production: Predictive maintenance, process optimization.

Logistics: Route optimization, real-time tracking.

Demand Management: Forecasting and trend analysis.

Customer Service: Demand-supply matching, personalized delivery options.

6. Transforming Supply Chains through Analytics

Analytics transforms traditional supply chains into smart, connected, and responsive networks.

Aspect	Traditional Supply Chain	Data-Driven Supply Chain
Decision Making	Experience-based	Data-driven and automated
Visibility	Limited	Real-time, end-to-end
Forecasting	Historical trend-based	Predictive and adaptive
Response Time	Slow	Fast and dynamic
Integration	Siloed	Seamless, collaborative

6.2 Transformation Areas

Planning: Demand sensing, scenario planning using predictive analytics.

Procurement: Supplier risk analysis, cost forecasting.

Production: Predictive maintenance, digital twins for process simulation.

Logistics: Dynamic routing, shipment visibility, warehouse optimization.

Customer Service: Improved order fulfillment and satisfaction tracking.

6.3 Benefits of Transformation

- Improved efficiency and cost control
- Enhanced collaboration across stakeholders
- Greater resilience and risk mitigation
- Sustainability through waste reduction
- Competitive advantage in dynamic markets

7. Barriers to Implementation of Data-Driven Supply Chains

Despite its benefits, organizations face several challenges:

Barrier	Description
Data Quality Issues	Incomplete, inaccurate, or inconsistent data reduces analytics accuracy.
Lack of Skilled Workforce	Shortage of data scientists and analytics professionals.
High Implementation Cost	Advanced analytics and technologies require substantial investment.
Resistance to Change	Employees and management may resist adopting new systems.
Data Silos	Lack of integration across departments and partners.
Cybersecurity Risks	Increased data exchange exposes systems to potential breaches.
Lack of Top Management Support	Strategic vision and leadership commitment are often missing.

8. Roadmap for Implementing Data-Driven Supply Chains

To successfully implement a data-driven supply chain, organizations can follow a structured roadmap:

Step 1: Define Objectives

Align analytics goals with overall business and supply chain strategy.

Identify key performance indicators (KPIs).

Step 2: Data Assessment

Evaluate existing data sources and quality.

Establish data governance and standardization processes.

Step 3: Infrastructure Development

Invest in cloud platforms, data warehouses, and IoT integration.

Ensure system interoperability.

Step 4: Analytics Capability Building

Develop internal analytics expertise.

Partner with analytics solution providers if needed.

Step 5: Pilot Projects

Start with small-scale use cases (e.g., demand forecasting).

Demonstrate quick wins to build confidence.

Step 6: Scale and Integrate

Expand analytics applications across all supply chain functions.

Ensure cross-functional collaboration.

Step 7: Continuous Improvement

Regularly review analytics outcomes.

Update models and strategies as business conditions change.

Unit-2

WAREHOUSING DECISIONS

Warehousing decisions are critical in supply chain management as they influence costs, service levels, and operational efficiency.

Effective warehousing involves determining the number, location, size, and layout of warehouses to optimize the total logistics cost while maintaining customer satisfaction.

1. Objectives of Warehousing Decisions

- To minimize total logistics cost (transportation, handling, storage).
- To ensure optimal customer service levels (timely delivery, product availability).
- To determine the optimal number and location of warehouses.
- To design the space and layout for efficient operations.

2. Mathematical Programming Models in Warehousing

Mathematical programming provides systematic methods to determine the optimal warehouse location and capacity decisions.

These models are used to minimize the total cost of transportation, inventory, and facility operation.

2.1 The P-Median Model

The P-Median Problem (PMP) is one of the most widely used facility location models in logistics and warehousing.

Objective:

To determine the optimal location of p warehouses (or facilities) to minimize the total distance or cost between customer demand points and warehouses.

Mathematical Formulation:

Let:

- $i = 1,2,\ldots,m$: Demand points (customers)
- $j = 1,2,\ldots,n$: Potential warehouse sites
- d_{ij}: Distance or cost between demand point $i$and warehouse j
- x_{ij}: Binary variable = 1 if demand point $i$is served by warehouse j, 0 otherwise
- y_j: Binary variable = 1 if a warehouse is located at site j, 0 otherwise
- p: Number of warehouses to be located

Objective Function:

$$\text{Minimize } Z = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij}x_{ij}$$

Subject to:

1. Each customer is assigned to one warehouse:

$$\sum_{j=1}^{n} x_{ij} = 1 \forall i$$

2. A customer can only be assigned to an open warehouse:

$$x_{ij} \le y_j \forall i,j$$

3. Exactly p warehouses are opened:

$$\sum_{j=1}^{n} y_j = p$$

4. Binary constraints:

$$x_{ij}, y_j \in \{0,1\}$$

Applications:

- Locating regional distribution centers.
- Determining service centers for minimizing delivery distances.

2.2 Guided Linear Programming (LP) Approach

The Guided LP approach is an iterative and heuristic-based method that uses Linear Programming to refine warehouse location decisions.

Steps:

1. Initial LP Model: Formulate a linear programming model considering transportation, operating, and fixed costs.
2. Guidance Mechanism: Introduce guidance parameters or weights to steer the LP solution toward feasible or practical results.
3. Iterative Improvement: Adjust parameters and re-run LP until an optimal or near-optimal location is achieved.

Advantages:

- Can handle multiple constraints.
- Provides near-optimal solutions with less computation time than integer programming.

Applications:

- Used in large-scale logistics networks where computational efficiency is required.

2.3 Balmer–Wolfe Method

The Balmer–Wolfe Method is a heuristic approach used for solving warehouse location problems.

Concept:

It combines cost analysis and heuristic optimization to find suitable warehouse locations without exhaustive computation.

Steps:

1. Estimate total distribution cost for each potential site.
2. Select the site with the lowest total cost as the first warehouse.
3. Add additional warehouses one by one, evaluating cost reduction at each step.
4. Continue until adding more warehouses does not reduce cost.

Features:

- Simple and computationally efficient.
- Useful for medium-sized problems where full optimization is complex.

2.4 Greedy Drop Heuristics

The Greedy Drop Heuristic is an iterative method that starts with a large number of potential warehouse locations and drops one location at a time to minimize total cost.

Steps:

1. Start with all candidate warehouse sites open.
2. Calculate total system cost (transportation + facility cost).
3. Evaluate the impact of closing each warehouse.
4. Drop the warehouse that increases cost the least.
5. Repeat until desired number of warehouses (p) remain.

Advantages:

- Simple and fast heuristic method.
- Provides a good approximation to the optimal solution.

Disadvantages:

- May not guarantee global optimality.

Applications:

- Used in large logistics networks where exact optimization is computationally expensive.

2.5 Dynamic Location Models

The Dynamic Location Model (DLM) considers time-dependent factors such as changing demand, cost structures, and capacity over a multi-period planning horizon.

Objective:

To determine when and where to open, close, or relocate warehouses to minimize total cost over time.

Mathematical Form:

$$\text{Minimize } Z = \sum_{t=1}^{T} \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij}^{t} x_{ij}^{t} + \sum_{t=1}^{T} \sum_{j=1}^{n} F_j^t y_j^t$$

Where:

- t: time period
- F_j^t: fixed cost of opening/operating a warehouse at location $j$in period t
- d_{ij}^t: transportation cost between customer $i$and warehouse $j$in period t

Features:

- Incorporates future demand and cost uncertainty.
- Facilitates long-term capacity and investment planning.

Applications:

- Strategic supply chain planning over multiple years.
- Industries with fluctuating demand patterns (e.g., retail, FMCG).

3. Space Determination and Layout Methods

Once the number and location of warehouses are determined, space allocation and layout design are crucial for efficient operations.

3.1 Space Determination

Determining warehouse space involves estimating required storage area, handling area, and supporting facilities.

Steps:

1. Forecast Inventory Levels: Based on demand, lead time, and service levels.
2. Calculate Storage Space Needs:

$$\text{Total Space Required} = \frac{\text{Average Inventory} \times \text{Storage Factor}}{\text{Utilization Rate}}$$

3. Add Space for Non-Storage Activities: (e.g., receiving, packing, offices).
4. Consider Expansion Needs: Plan for future growth and flexibility.

Factors Affecting Space:

- Product characteristics (size, weight, fragility).
- Material handling systems.
- Storage methods (pallets, racks, bins).

3.2 Layout Methods

The layout determines how materials flow within the warehouse. Efficient layouts minimize material handling time, distance, and congestion.

Common Layout Methods:

Layout Type	Description	Best Suited For
U-Shaped Layout	Receiving and shipping areas are adjacent, allowing efficient flow and minimal handling.	Small to medium warehouses

Layout Type	Description	Best Suited For
I-Shaped Layout	Straight-line flow from receiving to shipping.	Large high-throughput operations
L-Shaped Layout	Receiving and shipping at right angles; good for corner plots.	Medium facilities with moderate flow
Cross-Dock Layout	Goods move directly from inbound to outbound docks without storage.	Fast-moving goods, perishable items

Layout Planning Methods:

1. CRAFT (Computerized Relative Allocation of Facilities Technique): Iteratively improves layout by swapping departments to reduce material handling cost.
2. Systematic Layout Planning (SLP): Qualitative approach based on relationship charts and activity flow.
3. Space Relationship Diagram: Visual tool showing proximity importance between warehouse functions.

Key Considerations:

- Flow of materials (receiving → storage → picking → dispatch).
- Safety and ergonomic factors.
- Flexibility for expansion or automation.

4. Summary Table

Method	Type	Objective	Application
P-Median	Mathematical Model	Minimize total distance/cost	Optimal warehouse location
Guided LP	Heuristic-LP Hybrid	Cost optimization with constraints	Large logistics networks
Balmer–Wolfe	Heuristic	Stepwise cost reduction	Medium-scale problems
Greedy Drop	Heuristic	Eliminate least impactful sites	Approximation of optimal sites
Dynamic Location Model	Mathematical Model	Multi-period cost minimization	Long-term strategic planning
Space Determination	Quantitative	Estimate required space	Warehouse design
Layout Methods	Qualitative/Quantitative	Optimize material flow	Efficient operations

UNIT-III

1. Inventory Management Overview

Inventory management refers to the process of efficiently overseeing the constant flow of goods into and out of an existing inventory.

It ensures that the right quantity of inventory is available at the right place and time, minimizing costs and meeting demand effectively.

1.1 Objectives

- Maintain adequate supply to meet customer demand.
- Minimize holding, ordering, and shortage costs.
- Optimize working capital and cash flow.
- Improve service levels and operational efficiency.

2. Inventory Aggregation Models

2.1 Concept

Inventory aggregation (also called risk pooling) refers to combining inventory across multiple locations, products, or customers to reduce total inventory levels while maintaining or improving service levels.

2.2 Principle

When demands across different markets or products are pooled or aggregated, the variability of total demand decreases, which allows for reduced safety stock.

2.3 Types of Aggregation Models

Model Type	Description	Example
Location	Centralizing inventory at one or fewer	Central warehouse serving

Model Type	Description	Example
Aggregation	locations instead of multiple sites.	multiple regions.
Product Aggregation	Combining demand forecasts across multiple similar products.	Aggregating spare parts demand.
Temporal Aggregation	Grouping demand over a longer period.	Weekly vs. daily replenishment.

2.4 Benefits

- Reduced safety stock.
- Lower holding costs.
- Improved service levels due to demand smoothing.

2.5 Limitations

- Increased transportation costs or lead times.
- Higher risk of stockouts in decentralized regions.
- Complex coordination requirements.

3. Dynamic Lot Sizing Methods

3.1 Concept

Lot sizing determines how much to order and when to replenish inventory.

In a dynamic environment, demand varies over time, so lot sizing must adapt accordingly.

3.2 Common Methods

a. Wagner-Whitin Algorithm (Optimal)

- A dynamic programming approach to find the optimal lot size over multiple periods.
- Minimizes total cost (ordering + holding).
- Assumes deterministic demand and no shortages.

Key Feature: Finds global minimum cost solution but computationally intensive for large datasets.

b. Silver-Meal Heuristic

- Calculates the average cost per period and extends the lot until the cost per period starts to increase.
- Efficient for practical applications.

Formula:

$$\text{Average cost per period} = \frac{\text{Ordering cost + Holding cost}}{\text{Number of periods covered}}$$

c. Least Unit Cost (LUC) Method

- Chooses the lot size that minimizes the average cost per unit across the planning horizon.

d. Part-Period Balancing (PPB)

- Balances holding costs and ordering costs by equating them approximately.

3.3 Comparison

Method	**Optimality**	**Complexity**	**Use Case**
Wagner-Whitin	Optimal	High	Small to medium-scale problems
Silver-Meal	Heuristic	Moderate	Practical, dynamic demand
PPB	Heuristic	Low	Quick, approximate solution
LUC	Heuristic	Low	Useful for cost minimization

4. Multi-Echelon Inventory Models

4.1 Concept

A multi-echelon supply chain includes multiple levels or stages such as suppliers, manufacturers, distribution centers, and retailers.

Multi-echelon inventory models optimize inventory decisions across all echelons rather than at individual locations.

4.2 Objective

- Coordinate inventory control across multiple stages to minimize total system cost.
- Balance trade-offs between service levels, holding costs, and lead times.

4.3 Types of Multi-Echelon Models

Model	Description
Serial Systems	Inventory flows sequentially (Supplier → Manufacturer → Distributor → Retailer).
Distribution Systems	A central warehouse supplies multiple downstream retailers.
Assembly Systems	Multiple components from different suppliers are assembled into one product.

4.4 Key Models

- Clark–Scarf Model (1960): Foundational multi-echelon model for optimal stock levels.
- METRIC Model (Sherbrooke): For spare parts distribution in multi-echelon networks.

4.5 Benefits

- Reduces total inventory cost.
- Improves service level coordination.
- Enhances visibility across echelons.

4.6 Challenges

- Complex to model and optimize.
- Requires accurate lead time and demand data.
- High computational requirements.

5. Aggregate Inventory Systems and LIMIT

5.1 Aggregate Inventory Systems

Aggregate inventory management focuses on managing total inventory investment across all products and locations rather than item-by-item.

Objectives

- Maintain overall stock levels within budget.
- Balance service level and carrying cost.
- Support aggregate production planning and control.

5.2 Key Concepts

- ABC Classification: Prioritizing inventory items based on value or importance.
- Aggregate Measures: Total stock value, turnover ratio, and average inventory.

5.3 LIMIT – Linear Approximation Model for Inventory Management

LIMIT (Linear Approximation Model of Inventory Management and Targets)

- Developed by Holt, Modigliani, Muth, and Simon.
- It integrates inventory control, production planning, and workforce management in a linear programming framework.
- Helps determine optimal production and inventory levels given constraints.

Key Features:

- Balances production, holding, and shortage costs.
- Applicable in aggregate inventory and production planning.
- Supports managerial decision-making under fluctuating demand.

6. Risk Analysis in Supply Chains

6.1 Concept

Risk analysis in supply chain management identifies, assesses, and mitigates potential risks that disrupt material, information, and financial flows.

6.2 Types of Supply Chain Risks

Risk Type	Description	Examples
Transit Risk	Damage, delay, or loss during transportation.	Vehicle accidents, port delays.
Supply Risk	Disruptions in material or component supply.	Supplier bankruptcy, quality failure.
Delivery Risk	Inability to deliver on time to customers.	Late shipments, demand surges.
Operational Risk	Internal process failures.	Machine breakdowns, IT system failure.
Financial Risk	Price volatility or currency fluctuations.	Fuel cost increase, exchange rate shifts.
Environmental Risk	Natural disasters, sustainability failures.	Floods, regulatory non-compliance.

7. Measuring Supply Chain Risks

7.1 Measuring Transit Risks

- Probability of Damage or Loss (P): Based on historical data.
- Expected Transit Loss = P × Value of Goods
- Use insurance claim data or carrier reliability ratings.
- Employ real-time tracking (IoT, RFID) to monitor transit performance.

7.2 Measuring Supply Risks

- Supplier Reliability Index (SRI): Combines defect rate, lead time variability, and on-time delivery rate.

- Supplier Risk Score = f(Performance Variability, Financial Health, Geopolitical Risk).
- Techniques: Supplier audits, risk heat maps, and scenario analysis.

7.3 Measuring Delivery Risks

- On-Time Delivery Rate (OTD):

$$OTD = \frac{\text{Orders delivered on time}}{\text{Total orders}} \times 100$$

- Customer Service Level: Probability of meeting customer demand without stockout.
- Use root cause analysis for frequent delivery failures.

8. Risk Pooling Strategies

8.1 Concept

Risk pooling refers to the strategy of aggregating risks across multiple sources (locations, products, or suppliers) to reduce overall uncertainty and variability.

8.2 Techniques

Strategy	**Description**	**Example**
Inventory Centralization	Combine inventories at fewer locations to reduce safety stock.	One regional DC instead of many local warehouses.
Product Substitution	Allow substitutable products to fulfill demand.	Offering Model B if Model A is unavailable.
Flexible Supply Base	Multiple suppliers for critical components.	Dual sourcing for key materials.
Postponement	Delay product differentiation until demand is known.	Assemble-to-order production.
Information	Real-time data exchange between	Collaborative Planning, Forecasting,

Strategy	Description	Example
Sharing	partners.	and Replenishment (CPFR).

8.3 Benefits of Risk Pooling

- Reduces safety stock and variability.
- Enhances service levels and responsiveness.
- Increases supply chain resilience.

8.4 Limitations

- May increase lead times or logistics costs.
- Requires strong coordination and IT integration.
- Not all risks can be pooled (e.g., systemic risks like global pandemics).

Summary Table

Topic	Key Focus
Inventory Aggregation	Pooling inventory to reduce variability
Dynamic Lot Sizing	Optimal order quantities over time
Multi-Echelon Models	Coordinated inventory across supply chain stages
Aggregate Systems & LIMIT	System-level inventory and production control
Risk Analysis	Identifying and measuring supply chain risks
Risk Pooling	Combining risks to reduce overall uncertainty

UNIT-IV

1. Notion of Graphs

1.1 Definition

A graph (G) is a mathematical structure used to model pairwise relations between objects.

It consists of:

- Nodes (Vertices, V): Represent entities like cities, warehouses, or junctions.
- Arcs (Edges, E): Represent connections or routes between nodes.

1.2 Types of Graphs

Type	Description	Example
Directed Graph (Digraph)	Arcs have a direction (A → B).	Transportation routes with one-way streets.
Undirected Graph	Arcs have no direction.	Two-way roads.
Weighted Graph	Each edge has a cost, distance, or time associated.	Network with travel costs.
Network Graph	A graph used to model flow problems.	Distribution or supply chain networks.

1.3 Representation

- Adjacency Matrix – Matrix showing connections and weights.
- Adjacency List – List representation of connected nodes.

2. Minimal Spanning Tree (MST)

2.1 Definition

A spanning tree connects all nodes in a network without cycles using the minimum total cost or distance.

Objective:

$$\text{Minimize} \sum c_{ij}$$

subject to connecting all vertices.

2.2 Applications

- Designing minimum-cost communication or transportation networks.
- Laying pipelines, electrical lines, or rail routes.

2.3 Algorithms

a. Kruskal's Algorithm

1. Sort all edges in ascending order of cost.
2. Add the smallest edge that does not form a cycle.
3. Repeat until all vertices are connected.

b. Prim's Algorithm

1. Start with any vertex.
2. Add the least-cost edge connecting a new vertex.
3. Continue until all vertices are included.

3. Shortest Path Algorithms

3.1 Definition

Finds the path between two nodes that minimizes total cost, distance, or time.

3.2 Applications

- Optimal routing of shipments or delivery trucks.
- Navigation systems (e.g., GPS).
- Communication network routing.

3.3 Key Algorithms

Algorithm	Description	Features
Dijkstra's Algorithm	Finds the shortest path from a source node to all others.	Works with non-negative weights.
Bellman-Ford Algorithm	Handles graphs with negative edge weights.	Useful for dynamic systems.
Floyd-Warshall	Finds all-pairs shortest paths.	Used for dense graphs.

Algorithm	Description	Features
Algorithm		
A* (A-star)	Uses heuristic functions to speed up search.	Used in AI routing and logistics.

4. Maximal Flow Problems

4.1 Concept

Determines the maximum possible flow from a source node to a sink node in a network without exceeding capacity constraints.

4.2 Objective Function

$$\text{Maximize} \sum f_{ij}$$

subject to capacity $f_{ij} \leq c_{ij}$ and flow conservation at intermediate nodes.

4.3 Algorithms

- Ford–Fulkerson Method: Iteratively increases flow along augmenting paths.
- Edmonds–Karp Algorithm: Implementation of Ford–Fulkerson using BFS (Breadth-First Search).

4.4 Applications

- Pipeline capacity planning.
- Distribution and supply planning.
- Telecommunications and traffic flow management.

5. Multistage Transshipment and Transportation Problems

5.1 Transportation Problem

A linear programming model that minimizes total transportation cost while satisfying supply and demand constraints.

Objective Function:

$$\text{Minimize } Z = \sum_{i} \sum_{j} c_{ij} x_{ij}$$

subject to:

- Supply constraints: $\sum_j x_{ij} = s_i$
- Demand constraints: $\sum_i x_{ij} = d_j$
- $x_{ij} \geq 0$

5.2 Transshipment Problem

An extension of the transportation problem that allows goods to flow through intermediate nodes (transshipment points).

Example:

Factory → Warehouse → Retailers

Solving Methods:

- Linear Programming (LP)
- Network simplex method

5.3 Multistage Transshipment

Involves multiple intermediate stages between source and destination.

Used in multi-tier supply chains (suppliers → factories → DCs → customers).

6. Set Covering and Set Partitioning Problems

6.1 Set Covering Problem (SCP)

Objective: Select the smallest subset of available facilities (or routes) that "cover" all demand nodes.

Mathematical Formulation:

$$\text{Minimize} \sum_{j} c_j x_j$$

subject to

$$\sum_{j \in J_i} x_j \geq 1 \forall i$$

$$x_j \in \{0,1\}$$

Applications:

- Locating warehouses, fire stations, or service centers.
- Crew scheduling and vehicle dispatching.

6.2 Set Partitioning Problem (SPP)

Objective: Select a subset of feasible sets such that each element is covered exactly once.

Formulation:

$$\text{Minimize} \sum_{j} c_j x_j$$

subject to

$$\sum_{j \in J_i} x_j = 1 \forall i$$

$$x_j \in \{0,1\}$$

Applications:

- Airline crew scheduling.
- Transportation routing assignments.

7. Traveling Salesman Problem (TSP)

7.1 Concept

Finds the shortest possible route that visits each city exactly once and returns to the origin.

Objective Function:

$$\text{Minimize } Z = \sum_{i} \sum_{j} c_{ij} x_{ij}$$

subject to:

- Each city is visited once.
- The tour returns to the starting point.

7.2 Exact Methods

- Branch and Bound
- Dynamic Programming (Held–Karp Algorithm)

7.3 Heuristic Methods

Used for large, complex instances:

- Nearest Neighbor Heuristic
- 2-opt / 3-opt Improvement Heuristics
- Genetic Algorithms
- Simulated Annealing
- Ant Colony Optimization

7.4 Applications

- Delivery route planning.
- Circuit board drilling.
- Vehicle routing and logistics.

8. Advanced Vehicle Routing Problem (VRP) Heuristics

8.1 Concept

The VRP determines the optimal set of routes for a fleet of vehicles to deliver goods to a set of customers, minimizing total distance or cost, subject to vehicle capacity and route constraints.

8.2 Variants

- CVRP (Capacitated VRP): Vehicles have limited capacity.
- VRPTW (VRP with Time Windows): Customers must be served within specific times.
- MDVRP: Multiple depots.
- SDVRP: Split deliveries allowed.

8.3 Advanced Heuristic Approaches

Approach	Description
Savings Algorithm (Clarke & Wright)	Combines routes with maximum savings in cost.
Tabu Search	Uses memory-based metaheuristics to avoid local minima.
Genetic Algorithms (GA)	Uses crossover and mutation to evolve optimal routes.
Simulated Annealing (SA)	Probabilistically accepts worse solutions to escape local optima.
Ant Colony Optimization (ACO)	Mimics behavior of ants searching for shortest paths.
Hybrid Heuristics	Combines methods (e.g., GA + SA) for better results.

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9. Scheduling Algorithms

9.1 Concept

Scheduling determines the sequence and timing of jobs on machines or vehicles to optimize performance measures such as makespan, delay, or idle time.

9.2 Deficit Function Approach

Concept

- A deficit function measures the difference between desired and actual performance (e.g., lateness, delay, or cost).
- Scheduling algorithms attempt to minimize the total or maximum deficit across all jobs.

Deficit Function Example:

$$D_i(t) = \text{Desired Completion Time} - \text{Actual Completion Time}$$

Objective: Minimize $\sum D_i(t)$or $\max D_i(t)$

Applications:

- Production scheduling under due dates.
- Logistics scheduling to minimize delivery delays.

9.3 Linking Algorithms

Concept

Linking algorithms are coordination algorithms that integrate different scheduling or routing stages in multi-level systems.

Examples:

- Linking production schedules with transportation plans.
- Linking warehouse dispatch with vehicle routes.Use of hierarchical planning models where outputs of one stage serve as inputs to the next.

Benefits:

- Improves synchronization across supply chain stages.
- Reduces idle time and bottlenecks.
- Enables holistic optimization.

10. Summary Table

Topic	Objective	Key Algorithms / Methods
Graph Theory	Model network systems	Adjacency Matrix/List
Minimal Spanning Tree	Connect all nodes with minimal	Prim’s, Kruskal’s

Topic	Objective	Key Algorithms / Methods
	cost	
Shortest Path	Minimize travel distance/time	Dijkstra’s, Bellman-Ford
Maximal Flow	Maximize flow in a network	Ford–Fulkerson, Edmonds–Karp
Transportation Problem	Minimize transport cost	North-West Corner, MODI, Simplex
Transshipment	Include intermediate nodes	LP / Network Simplex
Set Covering / Partitioning	Select minimal or exact covering sets	Integer Programming
Traveling Salesman	Visit all nodes once at minimum cost	2-opt, 3-opt, GA, SA
VRP	Optimize multiple vehicle routes	Clarke–Wright, ACO, Tabu, Hybrid
Scheduling (Deficit/Linking)	Optimize timing and coordination	Deficit Minimization, Hierarchical Linking

UNIT-V

Multi-Criteria Decision-Making (MCDM) Models in Supply Chain Management

1. Introduction to MCDM

1.1 Definition

Multi-Criteria Decision-Making (MCDM) is a set of quantitative and qualitative methods used to **evaluate, rank, or select alternatives** when decisions involve **multiple conflicting criteria**.

In Supply Chain Management (SCM), MCDM helps decision-makers:

- Choose **suppliers**
- Select **transportation modes**
- Evaluate **inventory policies**
- Optimize **logistics networks**

1.2 Features of MCDM

- Considers **multiple objectives and constraints** (e.g., cost, quality, time, sustainability).
- Involves both **quantitative data** (cost, time) and **qualitative judgments** (trust, flexibility).
- Provides **structured and transparent** decision-making.

1.3 Common MCDM Models

1. Analytic Hierarchy Process (AHP)
2. Data Envelopment Analysis (DEA)
3. Fuzzy Logic and Fuzzy MCDM
4. Analytic Network Process (ANP)
5. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

2. Analytic Hierarchy Process (AHP)

2.1 Concept

Developed by **Thomas L. Saaty (1980)**, AHP is a **structured decision-making technique** that breaks down a complex problem into a **hierarchical model** of goals, criteria, sub-criteria, and alternatives.

2.2 Steps in AHP

1. **Define the Problem and Goal**
    - Example: Selecting the best supplier.
2. **Structure the Hierarchy**
    - **Level 1:** Goal (e.g., Best Supplier Selection)
    - **Level 2:** Criteria (Cost, Quality, Delivery, Reliability)
    - **Level 3:** Alternatives (Supplier A, B, C)
3. **Pairwise Comparison of Criteria**
    - Compare criteria in pairs using Saaty's **1–9 scale**, where
        - 1 = Equal importance,
        - 9 = Extreme importance of one over another.
4. **Calculate Priority Weights**
    - Compute normalized eigenvector of the comparison matrix to obtain **weights**.
5. **Consistency Check**
    - Compute **Consistency Ratio (CR)**:

$$CR = \frac{CI}{RI}$$

where $CI = \frac{\lambda_{max} - n}{n-1}$

- Acceptable if $CR < 0.1$.

6. **Synthesize Results**
    - Combine weights across hierarchy to rank alternatives.

2.3 Applications in SCM

- Supplier selection and evaluation.
- Logistics service provider selection.

- Facility location decisions.
- Prioritizing green supply chain initiatives.

2.4 Advantages and Limitations

Advantages	**Limitations**
Handles both qualitative and quantitative factors.	Time-consuming for large problems.
Provides consistency check.	Subjectivity in pairwise comparisons.
Easy to interpret and apply.	Doesn't handle interdependence among criteria.

3. Data Envelopment Analysis (DEA)

3.1 Concept

Data Envelopment Analysis (DEA) is a **non-parametric efficiency measurement method** based on **linear programming**.

It evaluates the **relative efficiency** of **Decision-Making Units (DMUs)** (e.g., suppliers, warehouses, transporters) using multiple **inputs** and **outputs**.

3.2 DEA Models

Model	**Type**	**Objective**
CCR Model (Charnes, Cooper, Rhodes)	Constant Returns to Scale (CRS)	Measures overall technical efficiency.
BCC Model (Banker, Charnes,	Variable Returns to	Separates scale efficiency from

Model	Type	Objective
Cooper)	Scale (VRS)	technical efficiency.

3.3 Mathematical Formulation (CCR Input-Oriented)

$$\text{Maximize } \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$$

subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, u_r, v_i \geq 0$$

where

- y_{rj}: Output r of DMU j
- x_{ij}: Input i of DMU j
- u_r, v_i: Weights

3.4 Applications in SCM

- Evaluating **supplier efficiency**.
- Benchmarking **logistics centers** or **distribution hubs**.
- Assessing **transportation performance**.
- Measuring **sustainability efficiency**.

3.5 Pros and Cons

Advantages	Limitations
Handles multiple inputs/outputs.	Sensitive to data quality.
Identifies best-performing units.	Cannot handle qualitative data.

Advantages	Limitations
No need for pre-defined weights.	Results are relative, not absolute.

4. Fuzzy Logic and Fuzzy MCDM Techniques

4.1 Concept

Fuzzy Logic, introduced by **Lotfi Zadeh (1965)**, deals with **imprecise and uncertain information**.

It is particularly useful when decisions involve **vague linguistic terms** like “high quality” or “low cost.”

4.2 Fuzzy Sets

Each element has a **membership degree** (μ) between **0 and 1**, representing how strongly it belongs to a set.

Example:

- “Cost is low” → $\mu = 0.8$
- “Delivery is fast” → $\mu = 0.9$

4.3 Common Fuzzy MCDM Methods

1. **Fuzzy AHP (FAHP):**
    - Incorporates fuzzy numbers (triangular or trapezoidal) in pairwise comparisons.
    - Reduces subjectivity in decision judgments.
2. **Fuzzy TOPSIS:**
    - Uses fuzzy data for distance measures to the ideal solution.
    - Handles uncertainty in expert opinions.
3. **Fuzzy Delphi:**
    - Uses fuzzy consensus among experts to define criteria weights.

4.4 Applications in SCM

- Supplier selection under uncertainty.
- Risk assessment and prioritization.
- Evaluating sustainability or green initiatives.
- Transport mode selection when data is vague.

4.5 Advantages

- Handles uncertainty and imprecision effectively.
- Reflects human reasoning and linguistic evaluation.
- Improves reliability of MCDM results.

5. Analytic Network Process (ANP)

5.1 Concept

The **Analytic Network Process (ANP)** is an **extension of AHP**, also developed by **Saaty**, which allows for **interdependencies and feedback** among decision elements.
Unlike AHP's hierarchical structure, ANP uses a **network structure** of clusters and nodes, where criteria may **influence each other**.

5.2 ANP Structure

- **Clusters:** Groups of elements (criteria, sub-criteria, alternatives).
- **Nodes:** Elements within clusters.
- **Interdependencies:** Links between nodes showing influence.

5.3 Steps in ANP

1. Model the decision problem as a **network**.
2. Conduct **pairwise comparisons** to obtain relative importance.
3. Form a **supermatrix** showing all relationships.

4. Compute the **limit matrix** to derive overall priorities.

5.4 Applications in SCM

- **Supplier selection** with interdependent criteria (e.g., cost ↔ quality ↔ delivery).
- **Strategic supply chain design** (balancing flexibility, responsiveness, and cost).
- **Sustainability trade-offs** among social, environmental, and economic factors.

5.5 Advantages

- Captures complex interrelationships.
- Provides more realistic decision representation than AHP.
- Applicable to dynamic and feedback-rich systems.

6. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)

6.1 Concept

Developed by **Hwang and Yoon (1981)**, **TOPSIS** ranks alternatives based on their **distance from an ideal solution** (best) and a **negative-ideal solution** (worst).

The best alternative is the one **closest to the ideal** and **farthest from the negative ideal**.

6.2 Steps in TOPSIS

1. **Construct Decision Matrix (X):**

   $X = [x_{ij}]$, where i = alternatives, j = criteria.

2. **Normalize the Matrix:**

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_i x_{ij}^2}}$$

3. **Weight the Normalized Matrix:**

$$v_{ij} = w_j \times r_{ij}$$

4. **Determine Ideal and Negative-Ideal Solutions:**
   - $A^+ = \{\max(v_{ij})\}$
   - $A^- = \{\min(v_{ij})\}$
5. **Calculate Euclidean Distances:**

$$S_i^+ = \sqrt{\sum_j (v_{ij} - A_j^+)^2}, S_i^- = \sqrt{\sum_j (v_{ij} - A_j^-)^2}$$

6. **Compute Closeness Coefficient (CC):**

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

7. **Rank Alternatives:**

   Higher $CC_i \Rightarrow$ Better performance.

6.3 Applications in SCM

- Selecting **optimal suppliers** or **logistics service providers**.
- Evaluating **transportation routes** or **warehousing locations**.
- Assessing **supply chain sustainability** alternatives.

6.4 Advantages

- Simple and logical method.
- Considers both best and worst conditions simultaneously.
- Works with both qualitative and quantitative criteria.

7. Comparative Summary of MCDM Models

Method	Key Principle	Best Used For	SCM Applications

Method	Key Principle	Best Used For	SCM Applications
AHP	Hierarchical pairwise comparisons	Structured problems with clear hierarchy	Supplier selection, facility location
DEA	Efficiency measurement	Comparing DMU performance	Logistics efficiency, supplier benchmarking
Fuzzy Logic	Uncertainty handling	Vague/linguistic judgments	Risk assessment, green SCM
ANP	Interdependent criteria	Complex, feedback systems	Sustainable supply chain decisions
TOPSIS	Distance from ideal solution	Ranking alternatives	Supplier and route selection