Supply Chain Analytics Using Python

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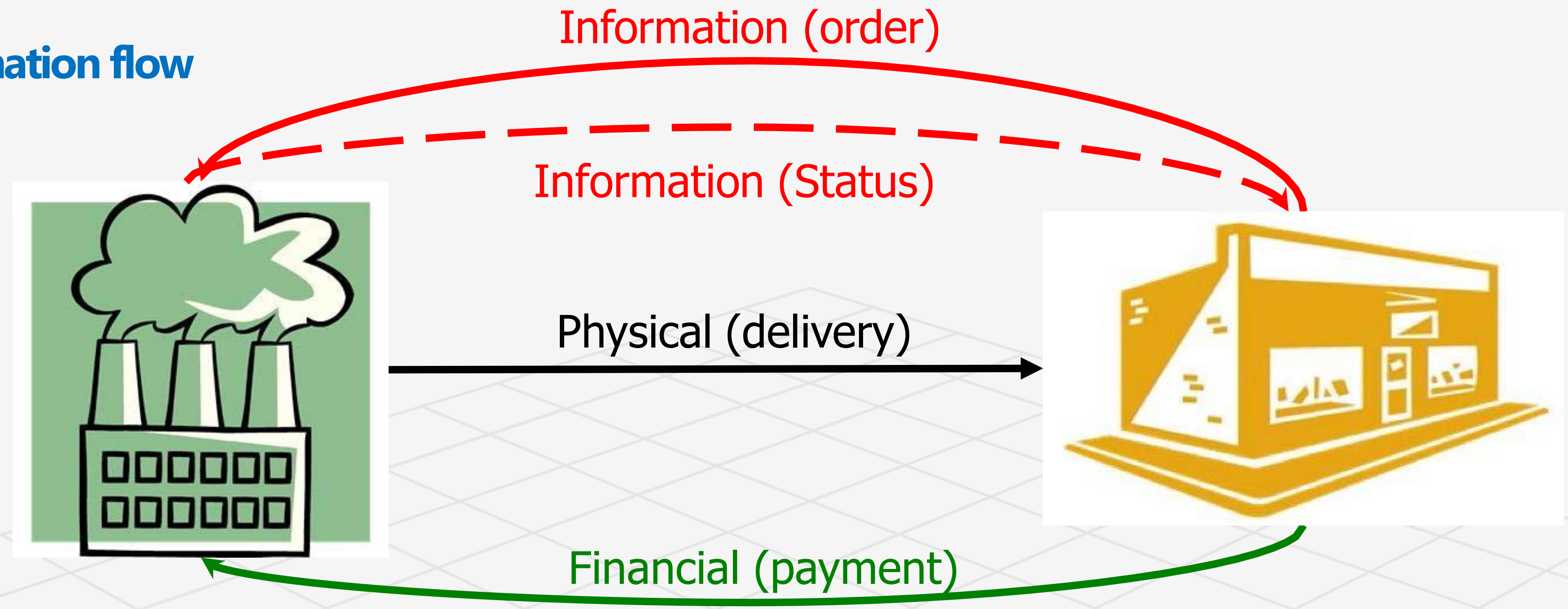
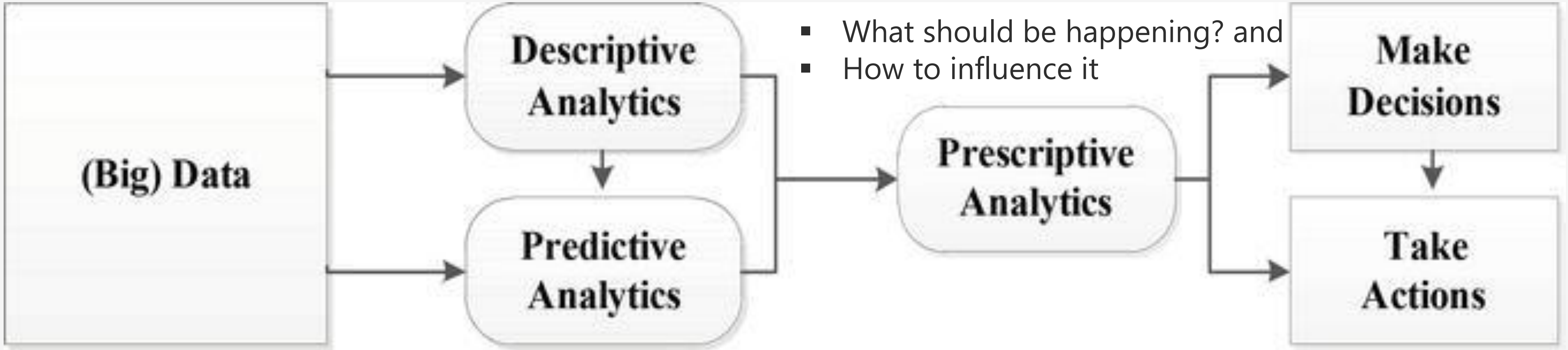
Supply Chain

- The **network of firms and facilities** involved in the transformation process from raw materials to a product and in the distribution of that product to customers.
- In a supply chain
  - **Physical flow**
  - **Financial flow**
  - **Information flow**



(Big) Data Analytics

- What has happened,
- What is happening, and
- Why



- What should be happening? and
- How to influence it

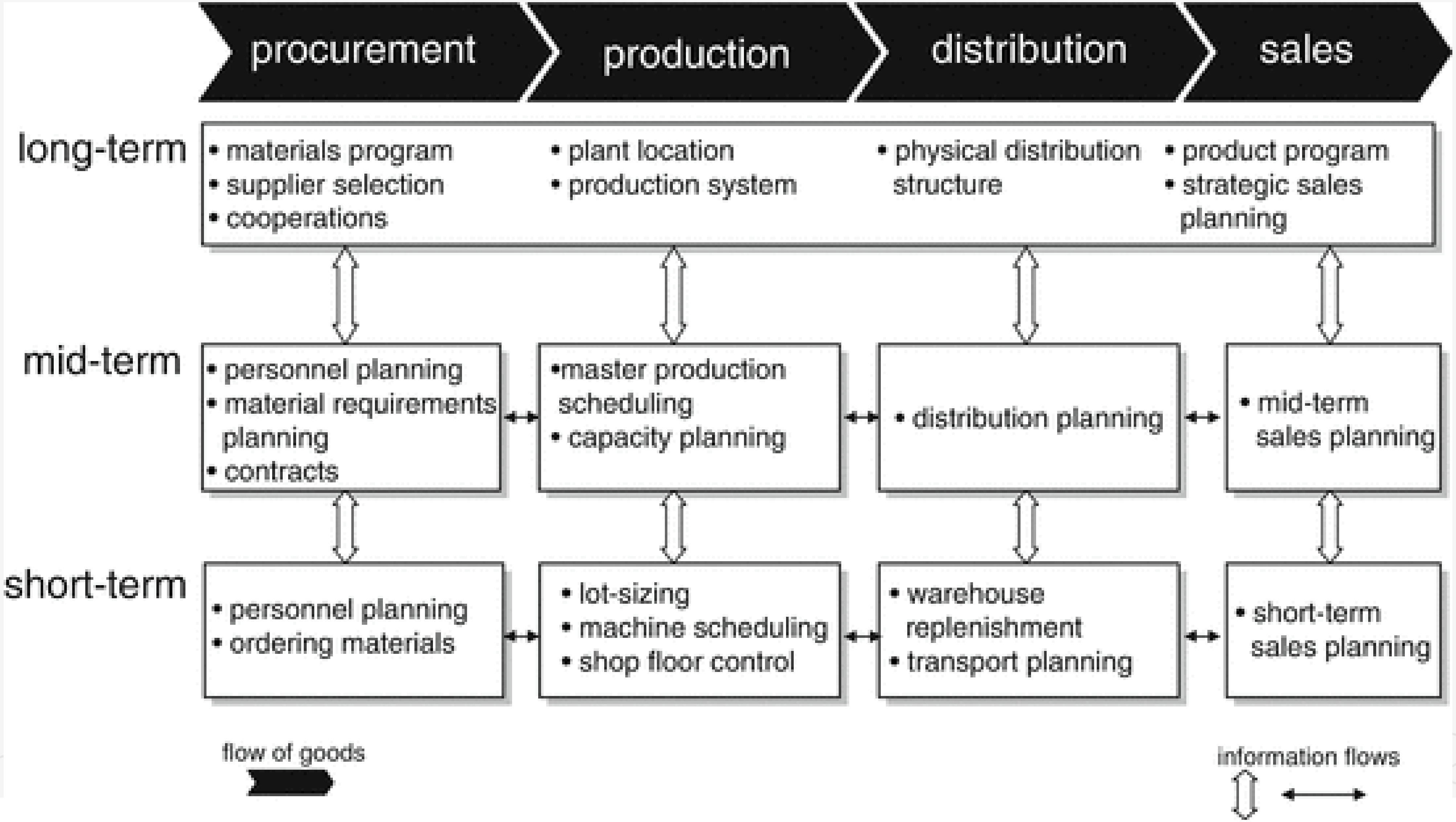
- What will be happening or likely to happen

Some of the crucial scenarios in Supply Chain that **prescriptive analytics** allows organization/companies to answer include:

- What kind of an offer should we make to each customer?
- What should be the plant / warehouse location?
- What should be the shipment strategy for each retail location?
- Which product should I launch and when?

Tiwari, S., Wee, H. M., & Daryanto, Y. (2018). Big data analytics in supply chain management between 2010 and 2016: Insights to industries. Computers & Industrial Engineering, 115, 319-330.

Supply Chain Planning Matrix



Supply Chain Planning & Supply Chain Operations Reference (SCOR) model

SCOR Domain	Source	Make	Deliver	Return
Activities	Order and receive materials and products	Schedule and manufacture, repair, remanufacture, or recycle materials and products	Receive, schedule, pick, pack, and ship orders	Request, approve, and determine disposal of products and assets
Strategic (time frame: years)	• Strategic sourcing • Supply chain mapping	• Location of plants • Product line mix at plants	• Location of distribution centers • Fleet planning	• Location of return centers
Tactical (time frame: months)	• Tactical sourcing • Supply chain contracts	• Product line rationalization • Sales and operations planning	• Transportation and distribution planning • Inventory policies at locations	• Reverse distribution plan
Operational (time frame: days)	• Materials requirement planning and inventory replenishment orders	• Workforce scheduling • Manufacturing, order tracking, and scheduling	• Vehicle routing (for deliveries)	• Vehicle routing (for returns collection)
Plan	Demand forecasting (long term, mid term, and short term)			

Souza, G. C. (2014). Supply chain analytics. Business Horizons, 57(5), 595-605.

Analytic Techniques used in Supply Chain Management

Analytics Techniques	Source	Make	Deliver	Return
Descriptive	• Supply chain mapping	• Supply chain visualization		
Predictive	• Time series methods (e.g., moving average, exponential smoothing, autoregressive models) • Linear, non-linear, and logistic regression • Data-mining techniques (e.g., cluster analysis, market basket analysis)			
Prescriptive	• Analytic hierarchy process • Game theory (e.g., auction design, contract design)	• Mixed-integer linear programming (MILP) • Non-linear programming	• Network flow algorithms • MILP • Stochastic dynamic programming	

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Mixed Integer Linear Programming

(LP) **Maximize** $z = \sum_j c_j x_j$

subject to $\sum_j a_{ij} x_j \leq b_i \quad (i = 1, 2, \ldots, m)$

$x_j \geq 0 \quad (j = 1, 2, \ldots, n)$

(MIP) **Maximize** $z = \sum_j c_j x_j + \sum_k d_k y_k$

subject to $\sum_j a_{ij} x_j + \sum_k g_{ik} y_k \leq b_i \quad (i = 1, 2, \ldots, m)$

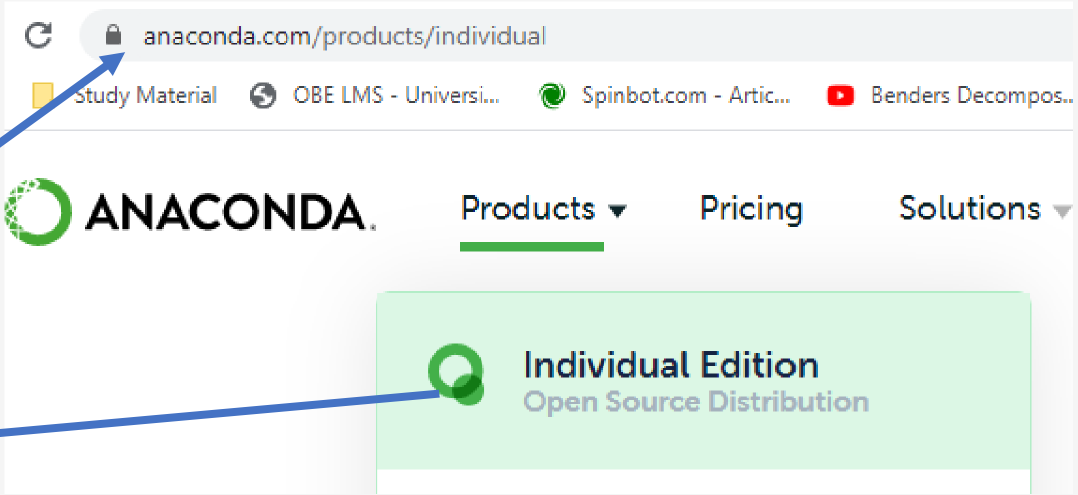
$x_j \geq 0 \quad (j = 1, 2, \ldots, n)$

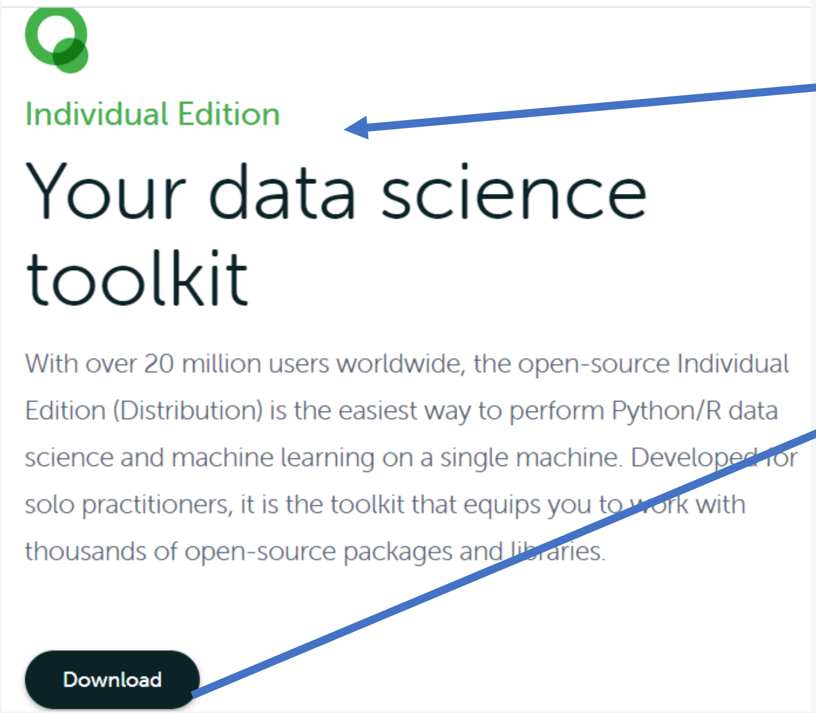
$y_k = 0, 1, 2, \ldots \quad (k = 1, 2, \ldots, p)$

Installation: Anaconda distribution

- **What is Anaconda distribution?**
  - Anaconda is a freemium open source distribution of the Python and R programming languages
  - It includes hundreds of popular data science packages

- **Official Website for Installing Anaconda**
  https://www.anaconda.com/products/individual





Install and Manage Package / Library in Python

pip package manager	**Conda** package manager
pip list	conda list
pip search packagename	conda search packagename
pip install packagename	conda install packagename
pip install packagename --upgrade	conda update packagename

Python Libraries for Optimization (Operations Research)

Paradigm[1]	Problem Form	Example Use Cases	Example Python Packages
Mathematical/Numerical			
Linear Programming	$\begin{array}{ll} \text{minimize} & \mathbf{c}^{\mathrm{T}}\mathbf{x} \\ \text{subject to} & A\mathbf{x} \le \mathbf{b} \\ \text{and} & \mathbf{x} \ge \mathbf{0} \end{array}$	• Supply chain optimization • Production planning	• PuLP: interface to linear and mixed-integer solvers • MIPCL: commercial mixed-integer programming • GLOP: Google's LP-only solver
Integer Programming	$\begin{array}{ll} \text{maximize} & \mathbf{c}^{\mathrm{T}}\mathbf{x} \\ \text{subject to} & A\mathbf{x} \le \mathbf{b}, \\ & \mathbf{x} \ge \mathbf{0}, \\ \text{and} & \mathbf{x} \in \mathbb{Z}^n, \end{array}$	• Minimize interference across cellular network • Bus scheduling/Vehicle routing • "Knapsack" problem	
Quadratic Programming	$\begin{array}{ll} \text{minimize} & \frac{1}{2}\mathbf{x}^{\mathrm{T}}Q\mathbf{x} + \mathbf{c}^{\mathrm{T}}\mathbf{x} \\ \text{subject to} & A\mathbf{x} \le \mathbf{b}, \end{array}$	• Financial portfolio optimization • Image/signals processing • Least-Squares regression	• qpsolvers: unified interface around quadratic solvers • quadprog: implementation of the Goldfarb/Idnani dual algorithm
Convex Optimization	$\begin{array}{ll} \text{minimize} & f(x) \\ \text{subject to} & g_i(x) \le 0, \quad i = 1, \ldots, m \end{array}$ $f, g_1 \ldots g_m : \mathbb{R}^n \to \mathbb{R}$ are all convex	• Training ML models • Linear/Quadratic are a special case of Convex	• cvxpy • cvxopt
Non-Linear Programming	$\begin{array}{l} \text{minimize } f(x) \\ \text{subject to } g_i(x) \le 0 \text{ for each } i \in \{1, \ldots, m\} \\ \qquad h_j(x) = 0 \text{ for each } j \in \{1, \ldots, p\} \\ \qquad x \in X. \end{array}$		• pyOpt
Multi-Paradigm			• Pyomo: multi-paradigm interface to multiple solvers • Google OR-Tools: Google's operations research tools • Gurobi: commercial optimizer supporting multiple languages • SciPy: its optimize package contains numerous solvers

What is PuLP?

https://coin-or.github.io/pulp/

- PuLP is **a modeling framework** for Linear (LP) and Integer Programing (IP) problems written in Python

- Maintained by COIN-OR Foundation (Computational Infrastructure for Operations Research)

- PuLP interfaces with different Solvers
    - CPLEX, COIN, Gurobi, etc…

Product Mix Problem : LP Model

A Company produces 3 paints (interior, exterior and theme) from two raw materials, M1 and M2.

Decision Variables:

- x_1 : Amount of exterior paint produced daily
- x_2 : Amount of interior paint produced daily
- x_3 : Amount of theme paint produced daily

Objective Function:

Maximizes the total daily profit

$$
\begin{aligned}
max \quad & Z = 1500x_1 + 2500x_2 + 3500x_3 \\
s.t. \quad & 2x_1 + 2x_2 + 3x_3 \leq 14 \\
& x_2 + 2x_3 \leq 5 \\
& x_1 \geq 0 \\
& x_2 \geq 0 \\
& x_3 \geq 0
\end{aligned}
$$

The Capacitated Plant (Facility) Location Problem : MIP Model

Consider a company with three potential sites for installing its facilities/warehouses and five demand points. Each site j has a yearly *activation cost (fixed cost)* f_j, i.e., an annual leasing expense that is incurred for using it, independently of the volume it services. This volume is limited to a given maximum amount that may be handled yearly, M_j. Additionally, there is a transportation cost c_{ij} per unit serviced from facility j to the demand point i. These data are shown in Table Data for the facility location problem: demand, transportation costs, fixed costs, and capacities.

Data for the facility location problem: demand, transportation costs, fixed costs, and capacities

Customer i	1	2	3	4	5		
Annual demand d_j	80	270	250	160	180		
Facility j	c_{ij}					f_j	M_j
1	4	5	6	8	10	1000	500
2	6	4	3	5	8	1000	500
3	9	7	4	3	4	1000	500

- ***Indices:***
  - n customers $i = 1,2, \dots, n$
  - m sites for facilities $j = 1,2, \dots, m$
- ***Decision Variables:***
  - $x_{ij} \geq 0 \rightarrow$ amount serviced from facility j to demand point i
  - $y_j = 1$ if a facility is established at location j, $y_j = 0$ otherwise.

$$\begin{array}{lll}
\text{minimize} & \sum_{j=1}^{m} f_j y_j + \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij} x_{ij} & \\
\text{subject to:} & \sum_{j=1}^{m} x_{ij} = d_i & \text{for } i = 1, \cdots, n \\
 & \sum_{i=1}^{n} x_{ij} \leq M_j y_j & \text{for } j = 1, \cdots, m \\
 & x_{ij} \leq d_i y_j & \text{for } i = 1, \cdots, n; j = 1, \cdots, m \\
 & x_{ij} \geq 0 & \text{for } i = 1, \cdots, n; j = 1, \cdots, m \\
 & y_j \in \{0,1\} & \text{for } j = 1, \cdots, m
\end{array}$$

Aggregate Production Planning: MIP Model

Assumption :

1. Hiring and firing are allowed in addition to using overtime from the regular work force.
2. Backorders are allowed.

Minimize = $\sum_{i=1}^{N}\sum_{t=1}^{T}[c_{it}\,X_{it} + h_{it}\,I_{it} + b_{it}B_{it}] + \sum_{t=1}^{T}[r_t\,R_t + o_t\,O_t + h_t\,H_t + f_t\,F_t]$

Subject to:

$X_{it} + I_{i^+,t-1} - I_{it^+} B_{i,t-1} + B_{it} = d_{it}$ $\quad \forall\, i, t \quad$ (Inventory-Balancing Constraints)

$\sum_{i=1}^{N} m_i X_{it} - R_t - O_t \leq 0$ $\quad \forall\, i, t \quad$ (Time Required to produce products)

$R_t - R_{t-1} - H_t + F_t = 0$ $\quad \forall\, i, t \quad$ (Regular Time Required)

$O_t - pR_t \leq 0$ $\quad \forall\, i, t \quad$ (Regular Time Required)

$R_t, O_t, H_t, F_t \geq 0$ $\quad \forall t \quad$ (Non-negative constraint)

$X_{it}, I_{it}, B_{it} \geq 0$ $\quad \forall\, i, t \quad$ (Non-negative constraint)

X_{it} (Integer)

Example: We will assume a unit production rate, that <u>overtime is at most 25% of regular labor</u>, <u>Initial Inventory is 3 units</u>, <u>Initial available regular hour and Backorders are 0 (Zero)</u>, and the data from the following table.

	Jan	Feb	Mar	Apr	May	Jun
Demand	100	100	150	200	150	100
Unit Production Cost (Excluding Labor)	7	8	8	8	7	8
Unit Holding Cost	3	4	4	4	3	2
Unit Backorder Cost	20	25	25	25	20	15
Unit Regular Labor Cost	15	15	18	18	15	15
Unit Overtime Labor Cost	22.5	22.5	27	27	22.5	22.5
Hiring Cost	20	20	20	20	20	20
Firing Cost	20	20	20	20	20	15

Transportation Problem: LP Model

Punjab Flour Mill has four branches A, B, C & D and four warehouses 1, 2, 3, and 4. Production, demand and transportation costs are given below:

PRODUCTION (TONES)	DEMAND (TONES)
A – 35	1 – 70
B – 50	2 – 30
C – 80	3 – 75
D – 65	4 – 55

Transportation Costs (in Rs):

	1	2	3	4
A	10	7	6	4
B	8	8	5	7
C	4	3	6	9
D	7	5	4	3

Find the optimal solution.

Let i index the sources, and j the destinations

m = # of sources, n = # destinations

Given:

S_i = quantity of goods available at source i

D_j = quantity of goods required at destination j

C_{ij} = unit cost of shipping goods from source i to destination j

Find:

X_{ij} = quantity of goods to be shipped from source i to destination j

Minimize $\sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}$

subject to

$$\sum_{j=1}^{n} X_{ij} \le S_i \quad \text{for } i=1, \dots m$$

$$\sum_{i=1}^{m} X_{ij} \ge D_j, \quad j=1, \dots n$$

$$X_{ij} \ge 0, \quad \text{all } i \text{ \& } j$$

Thanks!