UNIVERSITY AT BUFFALO
State University of New York
THE SCHOOL OF ENGINEERING AND APPLIED SCIENCES

IE 505
Production Planning and Control

Supply Chain Management

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Definitions

- "Supply Chain Management deals with the management of materials, information and financial flows in a network consisting of suppliers, manufacturers, distributors, and customers"
  -- Stanford SC Forum/ Dr. Hau Lee
- "SCM is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandize is produced and distributed at the right quantity, to the right locations, at the right time, in order to minimize systemwide costs while satisfying service level requirements"
  -- Dr. Simchi-Levi et al. (1999)

Definitions

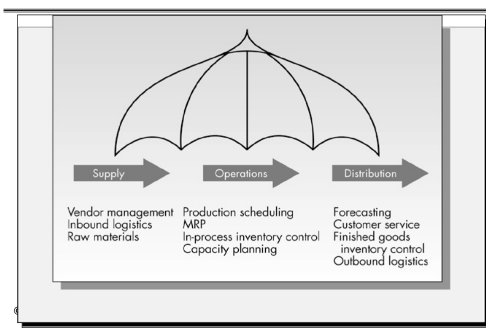
- "SCM is a continuously evolving management philosophy that seeks to unify the collective productive competencies and resources of a business function found both within the enterprise and outside the firm's allied business partners located along intersecting supply channels into a highly competitive, customer-enriching supply system focused on developing innovative solutions and synchronizing the flow of marketplace products, services, and information to create unique, individualized sources of customer value"
  -- Ross (1998)

Includes service organizations in addition to manufacturing

Definitions

- "Call it distribution or logistics or SCM… It is the sinuous, gritty, and cumbersome process by which companies move material, parts, and products to customers. …."
  -- Fortune Magazine/Henkoff (1994)
- "Structured business approach to balance, synchronize, and synergize all internal and external resources and assets." -- CAM-I
- "An integrative approach for planning and controlling the total flow through a distribution channel from suppliers to end users." -- Ashraf Alam

The Supply Chain Umbrella



Objectives of this Chapter

- Provide an appreciation for the most important issues encountered in managing complex supply chains.
- Present a sampling of the types of mathematical models used in SCM analysis
- Reading Assignment: Snapshot Application pf Wal-Mart, p. 307

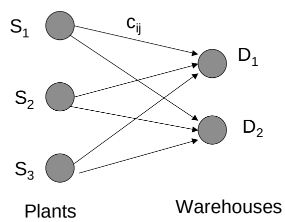
Transportation Problem

- Special case of Min Cost Flow Problem
- Shipping and Distribution Applications
- From plants to warehouses or warehouses to retailers, respectively
- Let there be *m* plants with known supplies (S_i corresponding to supply point *i*)
- And *n* warehouses with know demands (D_j corresponding to demand point *j*)
- Identify flows at min cost to satisfy demand from given supply (c_{ij} is unit shipping cost point *i*)

Transportation Problem

- Minimize $$\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$$
- S.t. $$\sum_{j=1}^{n} x_{ij} \le S_i \quad for \quad i = 1,2,\ldots m$$ $$\sum_{i=1}^{m} x_{ij} \ge D_i \quad for \quad j = 1,2,\ldots n$$ $$x_{ij} \ge 0 \quad for\ all \quad i,j$$

Transportation Network



Transportation Problem

- For the model to possess a feasible solution, total supply should be at least as large as total demand $$\sum_{i=1}^{m} S_i \ge \sum_{j=1}^{n} D_j$$
- It is convenient to assume equality by adding a dummy destination with remaining supply

Transportation Problem

- Simplex solution to an LP problem has at most k positive variables, where k is the number of independent constraints
- Convince yourself that there are M+n-1 independent constraints in the transportation problem
- Also note that a key result in network theory is that at least one optimal solution to the TP has integer-valued x_{ij} provided S_i and D_j are integers.

Standard Simplex

- Step 1: Select a set of m+n-1 routes that provide an initial basic feasible solution
- Step 2: Check whether the solution is improved by introducing a non basic variable. If so, go to Step 3; otherwise, Stop.
- Step 3: Determine which routes leave the basis when the variable that you selected in Step 2 enters.
- Step 4: Adjust the flows of the other basic routes. Return to Step 2.

Initial Solution

- Northwest corner rule
  - Algorithm: Begin by selecting X_{11} (that is, start in the northwest corner of the transportation simplex tableau). Thereafter, if X_{ij} was the last basic variable selected, then next select $X_{i,j+1}$ (that is, move one column to the right) if source i has any supply remaining. Otherwise, next select $X_{i+1,j}$ (that is, move one row down).

	1		2		3		4		Supply
A	8	(35)	6		10		9		35/0
B	9	(10)	12	(20)	13	(20)	7		50/40/20/0
C	14		9		16	(10)	5	(30)	40/30/0
Demand		45/10/0		20/0		30/10/0		30/0	

Initial Solution

- Northwest corner rule: Example

TABLE 8.16 Initial BF solution from the Northwest Corner Rule

		Destination 1		2		3		4		5		Supply	u_i
Source	1	16	(30)	16	(20)	13		22		17		50	
	2	14		14	(0)	13	(60)	19		15		60	
	3	19		19		20	(10)	23	(30)	M	(10)	50	
	4(D)	M		0		M		0		0	(50)	50	
Demand		30		20		70		30		60		Z = 2,470 + 10M	
	v_j												

Initial Solution

- Minimum Matrix Method
  - Algorithm: Find the minimum C_{ij} and assign to X_{ij} the higher of S_i or D_j. Reduce the demand and supply (S_i- X_{ij}; D_j- X_{ij}). Repeat until done. Note that the last arcs chosen could be very expensive.

	1		2		3		4		Supply
A	8	3 (15)	6	2 (20)	10		9		35/15/0
B	9	(30)	12		13	(20)	7		50/20/0
C	14		9		16	(10)	5	1 (30)	40/10/0
Demand		45/30/0		20/0		30/10/0		30/0	

Initial Solution

- Vogel's Approximation Method
  - Algorithm: For each row and column remaining under consideration, calculate its difference, which is defined as the arithmetic difference between the smallest and next-to-the-smallest unit cost C_{ij} still remaining in that row or column. (If two unit costs tie for being the smallest remaining in a row or column, then the difference is 0.) In that row or column having the largest difference, select the variable having the smallest remaining unit cost. (Ties for the largest difference, or for the smallest remaining unit cost, may be broken arbitrarily.)

TABLE 8.17 Initial BF solution from Vogel's approximation method

		Destination 1	2	3	4	5	Supply	Row Difference
Source	1	16	16	13	22	17	50	3
	2	14	14	13	19	15	60	1
	3	19	19	20	23	M	50	0
	4(D)	M	0	M	[0]	0	50	0
Demand		30	20	70	30	60	Select x_{44} = 30	
Column difference		2	14	0	(19)	15	Eliminate column 4	

		Destination 1	2	3	5	Supply	Row Difference
Source	1	16	16	13	17	50	3
	2	14	14	13	15	60	1
	3	19	19	20	M	50	0
	4(D)	M	0	M	[0]	20	0
Demand		30	20	70	60	Select x_{45} = 20	
Column difference		2	14	0	(15)	Eliminate row 4(D)	

		Destination 1	2	3	5	Supply	Row Difference
Source	1	16	16	[13]	17	50	(3)
	2	14	14	13	15	60	1
	3	19	19	20	M	50	0
Demand		30	20	70	40	Select x_{13} = 50	
Column difference		2	2	0	2	Eliminate row 1	

		Destination 1	2	3	5	Supply	Row Difference
Source	2	14	14	13	[15]	60	1
	3	19	19	20	M	50	0
Demand		30	20	20	40	Select x_{25} = 40	
Column difference		5	5	7	(M − 15)	Eliminate column 5	

		Destination 1	2	3	Supply	Row Difference
Source	2	14	14	[13]	20	1
	3	19	19	20	50	0
Demand		30	20	20	Select x_{23} = 20	
Column difference		5	5	(7)	Eliminate row 2	

		Destination 1	2	3	Supply
Source	3	19	19	20	50
Demand		30	20	0	Select x_{31} = 30, x_{32} = 20, x_{33} = 0

Z=2,460

Initial Solution

- Vogel's approximation method

	1		2		3		4		Supply	Row Diff
A	8		6		10		9		35	2
B	9		12		13		7		50	2
C	14		9		16		5	30	40/10	4
Demand		45		20		30		30/0		
Col Diff	1		3		3		2			

	1		2		3		4		Supply	Row Diff
A	8		6		10		9		35	2
B	9		12		13		7		50	3
C	14		9	10	16		5	30	40/10/0	5
Demand		45		20/10		30		30/0		
Col Diff	1		3		3					

Initial Solution

- Vogel's approximation method

	1		2		3		4		Supply	Row Diff
A	8		6	10	10		9		35/25	2
B	9		12		13		7		50	3
C	14		9	10	16		5	30	40/10/0	
Demand		45		20/10/0		30		30/0		
Col Diff	1		6		3					

	1		2		3		4		Supply	Row Diff
A	8		6	10	10	25	9		35/25/0	2
B	9	45	12		13	5	7		50/0	4
C	14		9	10	16		5	30	40/10/0	
Demand		45/0		20/10/0		30/0		30/0		
Col Diff	1		3							

Initial Solution

For ABC-> 1234 example

- Northwest corner rule $1,180
- Minimum Matrix Method $1,080
- Vogel's Approximation $1,020

Initial Solution

- Russell's approximation method
- Algorithm: For each source row i remaining under consideration, determine its $\bar{u}_i$ which is the largest unit cost C_{ij} still remaining in that row. For each destination column j remaining under consideration, determine its $\bar{v}_j$ which is the largest unit cost C_{ij} still remaining in that column. For each variable X_{ij} not previously selected in these rows and columns, calculate $\Delta_{ij} = C_{ij} - \bar{u}_i - \bar{v}_j$. Select the variable having the largest (in absolute terms) negative value of Δ_{ij} (Ties may be broken arbitrarily.)

TABLE 8.18 Initial BF solution from Russell's approximation method

Iteration	$\bar{u}_1$	$\bar{u}_2$	$\bar{u}_3$	$\bar{u}_4$	$\bar{v}_1$	$\bar{v}_2$	$\bar{v}_3$	$\bar{v}_4$	$\bar{v}_5$	Largest Negative Δ_{ij}	Allocation
1	22	19	M	M	M	19	M	23	M	$\Delta_{45} = -2M$	$x_{45} = 50$
2	22	19	M		19	19	20	23	M	$\Delta_{15} = -5 - M$	$x_{15} = 10$
3	22	19	23		19	19	20	23		$\Delta_{13} = -29$	$x_{13} = 40$
4		19	23		19	19	20	23		$\Delta_{23} = -26$	$x_{23} = 30$
5		19	23		19	19		23		$\Delta_{21} = -24$*	$x_{21} = 30$
6										Irrelevant	$x_{31} = 0$
											$x_{32} = 20$
											$x_{34} = 30$
											$Z = 2,570$

*Tie with $\Delta_{22} = -24$ broken arbitrarily.

Step 2: Optimality Test

- Dual Linear Program is
- Maximize $\sum_{i=1}^{m} S_i v_i + \sum_{j=1}^{n} D_j w_j$
- S.t. $v_i + w_j \le C_{ij} \quad for\ all \quad i = 1,2,\ldots m \quad j = 1,2,\ldots n$

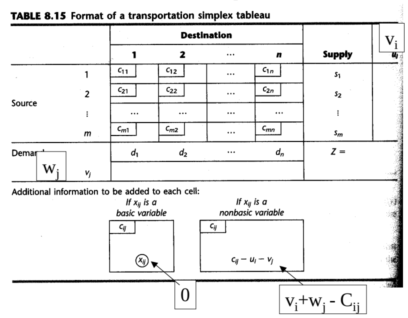
$where \quad v_i, \quad w_j \quad are\ unrestricted\ in\ sign$

- Theorem of complementary slackness gives:

$$\bar{C}_{ij} = v_i + w_j - C_{ij} \le 0 \quad if \quad x_{ij} = 0$$

$$\bar{C}_{ij} = v_i + w_j - C_{ij} = 0 \quad if \quad x_{ij} > 0$$

Format for Transportation Simplex



Example

	1		2		3		4		Supply
	2		3		11		7		
A									6
	1		0		6		1		
B									1
	5		8		15		9		
C									10
Demand		7		5		3		2	

Initial Basic Feasible Solution using Vogel's Approximation = 112

	1		2		3		4		Supply
	2		3		11		7		
A		6							6
	1		0		6		1		
B				1					1
	5		8		15		9		
C		1		4		3		2	10
Demand		7		5		3		2	

Example

- Finding v_i and w_j
- Set $v_A = 0$ arbitrarily to determine all other duals
- $v_A + w_2 - 6 = 0$; so $w_2 = 6$
- $v_C + w_2 - 9 = 0$; so $v_C = 3$
- $v_C + w_4 - 5 = 0$; so $w_4 = 2$
- $v_A + w_3 - 10 = 0$; so $w_3 = 0$
- $v_C + w_1 - 9 = 0$; so $w_1 = 6$, etc.

Example

- Step 3: Identify incoming variable (A2)

	1		2		3		4		v_I
	2		3		11		7		
A		0		2		1		-1	0
	1		0		6		1		
B		-4		0		1		0	-5
	5		8		15		9		
C		0		0		0		0	3
w_j		2		5		12		6	

- Identify which variable leaves (C2)

	1		2		3		4		Supply
	2		3		11		7		
A		6-z		z					6
	1		0		6		1		
B				1					1
	5		8		15		9		
C		1+z		4-z		3		2	10
Demand		7		5		3		2	

Example

- Step 4: Adjust the flows – find new basis (cost = 104)

	1		2		3		4		Supply
	2		3		11		7		
A		2		4					6
	1		0		6		1		
B				1					1
	5		8		15		9		
C		5		0		3		2	10
Demand		7		5		3		2	

- Step 3: Identify incoming variable (B3)

	1		2		3		4		v_I
	2		3		11		7		
A		0		0		1		-1	0
	1		0		6		1		
B		-2		0		3		2	-5
	5		8		15		9		
C		0		-2		0		0	3
w_j		2		3		12		6	

Example

- Step 3: Identify which variable leaves (B2)

	1		2		3		4		Supply
	2		3		11		7		
A		2-z		4+z					6
	1		0		6		1		
B				1-z		z			1
	5		8		15		9		
C		5+z				3-z		2	10
Demand		7		5		3		2	

- Step 4: Adjust the flows – find new basis (cost = 101)

	1		2		3		4		Supply
	2		3		11		7		
A		1		5					6
	1		0		6		1		
B				0		1			1
	5		8		15		9		
C		6		0		2		2	10
Demand		7		5		3		2	

Example

- Step 3: Identify incoming variable (A3)

	1		2		3		4		v_I
	2		3		11		7		
A		0		0		1		-1	0
	1		0		6		1		
B		-5		-3		0		-1	-5
	5		8		15		9		
C		0		-2		0		0	3
w_j		2		3		12		6	

- Identify which variable leaves (A1)

	1		2		3		4		Supply
	2		3		11		7		
A		1-z		5		z			6
	1		0		6		1		
B				0		1			1
	5		8		15		9		
C		6+z		0		2-z		2	10
Demand		7		5		3		2	

Example

- Step 4: Adjust the flows – find new basis (cost = 100)

	1		2		3		4		Supply
	2		3		11		7		
A		0		5		1			6
	1		0		6		1		
B						1			1
	5		8		15		9		
C		7				1		2	10
Demand		7		5		3		2	

- Step 3: Test for optimality again

	1		2		3		4		v_I
	2		3		11		7		
A		-1		0		0		-2	0
	1		0		6		1		
B		-5		-2		0		2	-5
	5		8		15		9		
C		0		-1		0		0	4
w_j		1		3		11		5	

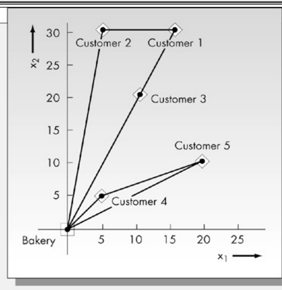
Distribution Resource Planning (DRP)

- MRP logic to manage distribution systems (Martin, 1990).
- Advantage over ROP systems is that it can deal with changing demand patterns
- However it ignores uncertainty

DRP-Based Order Profile for Blue Books

On hand	26								
Order leadtime	2 weeks								
Safety stock	0								
Weeks:	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Sales forecasts		22	35	60	12	0	19	85	33
In transit		40							
On order			26						
Projected balance	26	44	35	12	0	0	−19		
Planned shipments order date		37							
Planned shipments receipt date				37					

Delivery Routes in Supply Chains



Practical Issues in Vehicle Scheduling

- Vehicle Scheduling Problems are of two types
  - Arc-based (e.g., snow removal, garbage collection)
  - Node-based (e.g., collection and distribution)
- Schrage (1981) list these features:

1. Frequency Requirements (e.g., daily)
2. Time Windows
3. Time dependent travel times

Practical Issues in Vehicle Scheduling

4. Multidimensional capacity constraints (weight/volume)
5. Vehicle types (different capacities and costs)
6. Split deliveries (more than 1 vehicle to a customer)
7. Uncertainty (e.g., traffic conditions, weather, vehicle breakdowns)

Designing Products for Supply Chain Efficiency

- Historically Product Design has been “throw over the wall” to manufacturing.
- In recent past we have
  - Design For Manufacturing (DFM)
  - Concurrent Engineering
- Now –
  - Design for Logistics (DFL)
  - Three-dimensional concurrent engineering (3-DCE): Products, Processes, and Supply Chains

Designing Products for Supply Chain Efficiency

- How logistics considerations enter design
  - Product design for efficient transportation and shipment
  - Delayed differentiation (Postponement of final product configuration)
    - Benetton: Dyeing sweaters after knitting (“gray stock”)
    - HP: Localization of printers (correct power supply + plug) can be done at DC rather than factories
- Additional issues
  - The configuration of the supplier base
  - Outsourcing arrangement (3PL)
  - Channels of distribution (DCs, 3P wholesalers, licensing, or direct selling)

Role of Information in SCM

- The Case of Pasta Barilla (Harvard B School)
- Barilla is an Italian manufacturer of pasta
- In late 1980s the head of logistics tried to introduce a new distribution approach JITD
- The idea was to get the distributor sales #s and Barilla would decide when and how large should the deliveries be.
- At that time distributors would independently place weekly orders based on std reorder point methods. This would cause large swings in demand for Barilla’s factories due to the “Bullwhip Effect”
- The change was met with great resistance but adopted

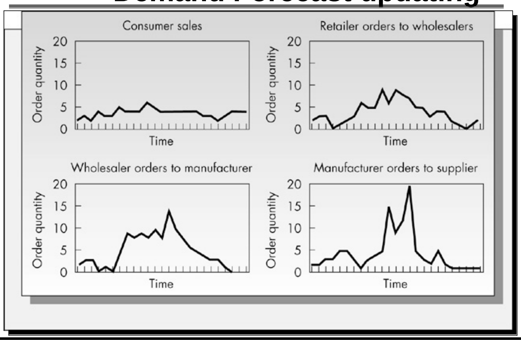
Role of Information in SCM

- The Case of Pasta Barilla (cont.)
- JITD system was implemented with striking results
- It was a win-win for Barilla and its distributors
- This is known as "Vendor Managed Inventory" or VMI today
- Now, Proctor and Gamble has accepted VMI for Wal-Mart, etc.

Role of Information in SCM Bullwhip Effect

- Industry and academics realized that the orders placed by distributors had much more variance than sales at retail stores.
- P&G coined the term "bullwhip" effect
- Where does it come from?
  - Demand Forecast updating
  - Order batching at stages causes spiky demands to previous suppliers
  - Price fluctuations
  - Shortage gaming

Bullwhip Effect: Causes Demand Forecast updating



Bullwhip Effect: Causes

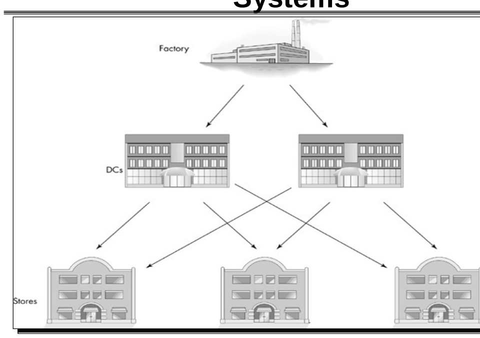
- Order Batching
  - We will see this in MRP systems too, order batching (EOQ-type) translates a smooth demand pattern into spiky demand at "lower" levels
- Price fluctuations
  - "forward buying" due to attractive prices
- Shortage gaming
  - When product is in short supply the manufacturer places customers on allocation, so the customers inflate demand to make up for expected shortfall.

Bullwhip Effect: Elimination*

- Information Sharing
  - All parties share POS data (for forecasts also). Fortunately, IT has helped – EDI, for instance.
- Channel Alignment
  - Reduction of fixed costs (ordering cost via EDI; transportation costs by mixed product and LTL shipments or outsourcing – 3rd party logistics)
- Price Stabilization
  - Value-pricing rather than promotional pricing
- Discouragement of Shortage Gaming
  - Allocate based on past sales rather than orders.

* Lee, Padmanabhan, and Whang (1997)

Multilevel Distribution Systems



Multilevel Distribution Systems

- Advantages of intermediate storage
  - Risk pooling (aggregate demand has lower variation)
  - DCs can be designed to meet local needs
  - Economies of scale in storage and movement
  - Faster response time
- Disadvantages
  - May require more inventory
  - May increase total order lead times
  - Could result in higher cost of storage and movement
  - Could contribute to the bullwhip effect.
- Reading Assignment § 6.10 pp. 346-351 on "Designing the SC in a Global Environment"