IE426: Supply Chain Management
Homework #1
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Question 1

(a)

ROE, ROA, APT, ART, INVT, PPET, and C2C were calculated. The results are provided in Fig. 1 with the previous results of Amazon and Nordstrom. The figure above is a copy of the first sheet in the file named 'Homework Assignment 1 - Jaewoo Kim.xlsx' that contains the detailed calculation. The following equations were used for the calculation [1]:

$$ROE = \frac{Net\ Income}{Average\ Shareholder\ Equity} \tag{1}$$

$$ROA = \frac{Net\ Income + [Interest\ Expense \times (1 - Tax\ Rate)]}{Average\ Total\ Assets} \tag{2}$$

$$APT = \frac{Costs\ of\ Goods\ Sold}{Accounts\ Payable} \tag{3}$$

$$ART = \frac{Sales\ Revenue}{Accounts\ Receivable} \tag{4}$$

$$INVT = \frac{Cost\ of\ Good\ Sold}{Inventory} \tag{5}$$

$$PPET = \frac{Sales\ Revenue}{PP\ \&\ E} \tag{6}$$

$$C2C = -Weeks\ Payable\ (1/APT) + WeeksinInventory\ (1/INVT) + Weeks\ Receivable\ (1/ART) \tag{7}$$

(b)

ROE and ROA represent the income generated relative to equity and assets, respectively. Among the companies, Amazon produces the lowest returns compared to its investments and assets. From another angle, we can say that Amazon's vast infrastructure and funds outweigh its current income.

A higher APT value indicates faster payment to suppliers, while a higher ART value implies quicker collection of sales revenue from customers. The APT values across the companies show variation from 2.48 (Amazon) to 7.35 (Nordstrom), implying that the mean payment lead time from 7.1 weeks (=1/7.35 years, Nordstrom) to 21.0 weeks (=1/2.48 years, Amazon). In contrast, the ART values differ more significantly. Walmart and Macys receive revenues much faster than the other two companies, with values of 69.32 and 75.29, respectively. These values imply that Walmart and Macy's receive their sales revenue within a week. It is likely due to face-to-face transactions in physical stores where customers often pay in cash. On the other hand, Nordstrom has the lowest ART value, possibly due to the nature of its business, as it operates within department stores and relies on multiple processes involving credit card companies and department store systems for revenue collection.

A higher INVT value reflects a faster inventory cycle. Walmart and Amazon have high INVT values of 8.05 and 7.31, respectively, indicating they use their inventory swiftly. For example, Walmart cycles through its entire inventory in approximately 6.5 weeks (=1/8.05 years), while Amazon does so in about 7.1 weeks (=1/7.31 years). Macys has the lowest INVT value at 3.15, meaning its inventory stays in storage for about 16.5 weeks (=1/3.15 years) before being sold.

Year ended January 31, 2013 ($M)	Wallmart	Macy's		
Net operating revenues	469,162	27,931		
Cost of goods sold	352,488	16,725		
Gross profit	116,674	11,206		
Selling, general, and administrative expense	88,873	8,440		
Other costs		88		
Operating income	27,801	2,678		
Interest expense	2,251	388		
Other income(loss)—net	187	134		
Income before income taxes	25,737	2,290		
Income taxes	7,981	804		
Net income	17,756	1,486		
Assets				
Cash and cash equivalents	7,781	1,836		
Net receivables	6,768	371		
Inventory	43,803	5,308		
Prepaid expenses and other	1,588	361		
Total current assets	59,940	7,876		
Property, plane, and equipment	116,681	8,196		
Goodwill	20,497	3,743		
Other intangible assets		561		
Other assets	5,987	615		
Total assets	203,105	20,991		
Liabilities and Stockholder Equity				
Accounts payable	59,099	4,951		
Short-term debt	12,719	124		
Total current liability	71,818	5,075		
Long-term debt	41,417	6,806		
Other liabilities		3,059		
Total liabilities	121,367	14,940		
Stockholder equity	81,738	6,051		
Tax rate	35%			
Weeks/year	52			
Performance Metrics	**Wallmart**	**Macy's**	**Amazon.com**	**Nordstrom Inc.**
Return on Equity (ROE), -	21.72%	24.56%	2.81%	38.42%
Return on Assets (ROA), -	9.46%	8.93%	0.91%	10.37%
Accounts Payable Turnover (APT), -	5.96	3.38	2.48	7.35
Accounts Receivable Turnover (ART), -	69.32	75.29	15.62	5.71
Inventory Turnover (INVT), -	8.05	3.15	7.31	5.46
Property, Plane, and Equipment Turnover (PPET), -	4.02	3.41	6.80	4.71
Cash-to-Cash Cycle (C2C), weeks	-1.51	1.80	-10.53	11.56

Figure 1: Performance metrics calculation for Q1-a

A higher PPET value indicates that a company effectively utilizes its facilities to generate investment returns. Amazon demonstrates the best performance, with a PPET value of 6.80, while Macy's shows the lowest performance, with a value of 3.41.

C2C measures the time a company needs to move from sourcing goods to receiving cash from sales. Amazon has an exceptionally low C2C value, 10.53 weeks, indicating it collects cash before needing to pay suppliers. In contrast, Nordstrom has the slowest cycle, with a C2C value of 11.56 weeks, reflecting a longer process to convert its investments in supply into cash.

Question 2

The optimization formulation used in Question 2 is as follows.

$$\min_{\mathbf{x},\mathbf{y}} \sum_{i\in I} f_i y_i + \sum_{i\in I, j\in J} c_{ij} x_{ij} \tag{8}$$

$$\sum_{i\in I} x_{ij} = D_j, \quad \forall j \in J \tag{9}$$

$$\sum_{j\in J} x_{ij} \leq K_i y_i, \quad \forall i \in I \tag{10}$$

$$\mathbf{x} \in \mathbb{Z}_+^{|I|\times|J|} \tag{11}$$

$$\mathbf{y} \in \{0,1\}^{|I|} \tag{12}$$

Here, i ($\in I$) and j ($\in J$) are indices for home offices and the sites to visit, respectively. There are two kinds of decision variables: x_{ij} represents the number of trips to site j covered by home office i, y_i indicates whether home office i is open (=1) or closed (=0). The objective function, Eq. (8), consists of the fixed cost (or facility cost, the first term) and the variable cost (or travel cost, the second term). Eq. (9) is a constraint that ensures all consulting demands are met, where D_j is the demand from the site j. Eq. (10) is a constraint that limits each office's capacity, where the home office's capacity at i is K_i.

(a)

Since no capacity constraint exists for this case, I set K_i as $\sum_{j\in J} D_j$ for all $i \in I$ so that Eq. (10) is inactive. The optimization formulation and solution procedure are implemented in an Excel sheet, as shown in Fig. 2. The yellow, red, and green boxes highlight the decision variables, constraints, and objective function, respectively. Specifically, the larger yellow box corresponds to **x**, and the smaller yellow box corresponds to **y**. The vertical red box represents Eq. (9), while the horizontal red box represents Eq. (10).

The solution seems reasonable since the facility cost is exceptionally high, and this example has no facility capacity limits. As a result, selecting one facility and fully utilizing it is the most efficient strategy, as shown in the optimal solution. Denver is chosen as the most promising location for the home office.

The facility cost is \$140,000, and the travel cost is \$79,500. A total of 27 consultants should be assigned to this single home office.

(b)

Since this case limits the number of consultants assigned to each home office to 10, this is reflected by setting $K_i = 250$ (=25 trips/consultant $\times$ 10 consultants).

The objective function is significantly higher than in the previous case because the capacity constraint restricts the solution space more.

Notably, Denver is again selected, this time as one of the three home offices, along with Seattle and Tulsa. Additionally, both Denver and Seattle utilize their full capacity, with 10 consultants and 250 trips each, while the Tulsa office assigns 7 consultants, accounting for 175 trips.

State	Trips from LA	Trips from Tulsa	Trips from Denver	Trips from Seattle	Total # of trips	Unmet needs
Washington	-	-	40	-	40	-
Oregon	-	-	35	-	35	-
California	-	-	100	-	100	-
Idaho	-	-	25	-	25	-
Nevada	-	-	40	-	40	-
Montana	-	-	25	-	25	-
Wyoming	-	-	50	-	50	-
Utah	-	-	30	-	30	-
Arizona	-	-	50	-	50	-
Colorado	-	-	65	-	65	-
New Mexico	-	-	40	-	40	-
North Dakota	-	-	30	-	30	-
South Dakota	-	-	20	-	20	-
Nebraska	-	-	30	-	30	-
Kansas	-	-	40	-	40	-
Oklahoma	-	-	55	-	55	-
Total # of trips	-	-	675	-		
Open(=1) or closed(=0)	-	-	1	-		
Leftover capacity	-	-	-	-		
Total # of consultants	0	0	27	0		
Fixed cost, $	165,428	131,230	140,000	145,000		
Facility Cost, $	140,000					
Travel Cost, $	79,500					
Total Cost, $	219,500					

Figure 2: Solution of Q2-a

State	Trips from LA	Trips from Tulsa	Trips from Denver	Trips from Seattle	Total # of trips	Unmet needs
Washington	-	-	-	40	40	-
Oregon	-	-	-	35	35	-
California	-	-	-	100	100	-
Idaho	-	-	-	25	25	-
Nevada	-	-	15	25	40	-
Montana	-	-	-	25	25	-
Wyoming	-	-	50	-	50	-
Utah	-	10	20	-	30	-
Arizona	-	-	50	-	50	-
Colorado	-	-	65	-	65	-
New Mexico	-	40	-	-	40	-
North Dakota	-	-	30	-	30	-
South Dakota	-	-	20	-	20	-
Nebraska	-	30	-	-	30	-
Kansas	-	40	-	-	40	-
Oklahoma	-	55	-	-	55	-
Total # of trips	-	175	250	250		
Open(=1) or closed(=0)	-	1	1	1		
Leftover capacity	-	75	-	-		
Total # of consultants	0	7	10	10		
Fixed cost, $	165,428	131,230	140,000	145,000		
Facility Cost, $	416,230					
Travel Cost, $	62,500					
Total Cost, $	478,730					

Figure 3: Solution of Q2-b

Question 3

(a)

The total costs are the sum of the fixed costs, variable costs (or production costs), and transportation costs. The total cost is calculated as $ 87,961,400 (Fig. 4). Note that in the case of wipes, the transportation costs are much higher than the fixed costs, but the difference is not that significant in the case of ointment.

		Northwest	Southwest	Upper Midwest	Lower Midwest	Northeast	Southeast	Capacity	Open (=1) or closed (=0)	Facility usage	Leftover capacity
Wipes	Chicago	500	700	900	800	1,000	600	5,000	1	4,500	500
	Princeton, NJ	0	0	0	0	0	0	2,000	0	0	2,000
	Atlanta	0	0	0	0	0	0	2,000	0	0	2,000
	LA	0	0	0	0	0	0	2,000	0	0	2,000
	Unmet Demand	0	0	0	0	0	0				
Ointment	Chicago	50	90	120	65	120	70	1,000	1	515	485
	Princeton, NJ	0	0	0	0	0	0	1,000	0	0	1,000
	Atlanta	0	0	0	0	0	0	1,000	0	0	1,000
	LA	0	0	0	0	0	0	1,000	0	0	1,000
	Unmet demand	0	0	0	0	0	0				

	Wipes	Ointment
Fixed cost, $	5,000,000	1,500,000
Production cost, $	45,000,000	10,300,000
Transportation cost, $	23,464,000	2,697,400

Total cost, $	87,961,400

Figure 4: Solution of Q3-a

(b)

To answer this question, the optimization problem below is solved.

$$\min_{\mathbf{x},\mathbf{y}} \sum_{s\in S}\left(\sum_{i\in I} f_{si}y_{si} + \sum_{i\in I, j\in J} c_{sij}x_{sij}\right) \tag{13}$$

$$\sum_{s\in S}\sum_{i\in I} x_{sij} = D_{sj}, \quad \forall s \in S, \forall j \in J \tag{14}$$

$$\sum_{s\in S}\sum_{j\in J} x_{sij} \leq K_{si}y_{si}, \quad \forall s \in S, \forall i \in I \tag{15}$$

$$\mathbf{x} \in \mathbb{Z}_{+}^{|S|\times|I|\times|J|} \tag{16}$$

$$\mathbf{y} \in \{0,1\}^{|S|\times|I|} \tag{17}$$

This formulation is similar to that in Question 2. The only difference is the introduction of the index s and its admissible value set S, which indicates different items (i.e., wipes and ointment). Additionally, since the facility in Chicago has already been constructed, the corresponding y variables should be fixed at 1. That is, the following constraints are included:

$$y_{si} = 1, \quad i = 1, \forall s \in S \tag{18}$$

, where 1 is the index for Chicago facilities. However, for the code implementation, the corresponding y variables are excluded as decision variables and fixed as 1 instead of introducing these new constraints.

Like Question 2, the decision variables, constraints, and objective function are represented by yellow, red, and green boxes in Fig. 5 to Fig. 7, with varying transportation costs. The two 2D arrays with yellow boxes correspond to $\mathbf{x}$, while the vertical 1D arrays with yellow boxes represent $\mathbf{y}$. Note that the y variables for Chicago are not included as decision variables. The two horizontal red boxes correspond to Eq. (14), and the two vertical red boxes correspond to Eq. (15). The objective function, total costs, is highlighted by a green box.

		Northwest	Southwest	Upper Midwest	Lower Midwest	Northeast	Southeast	Capacity	Open (=1) or closed (=0)	Facility usage	Leftover capacity
Wipes	Chicago	0	0	900	800	0	0	5,000	1	1,700	3,300
	Princeton, NJ	0	0	0	0	0	0	2,000	0	0	0
	Atlanta	0	0	0	0	1,000	600	2,000	1	1,600	400
	LA	500	700	0	0	0	0	2,000	1	1,200	800
	Unmet Demand	0	0	0	0	0	0				
Ointment	Chicago	50	90	120	65	120	70	1,000	1	515	485
	Princeton, NJ	0	0	0	0	0	0	1,000	0	0	0
	Atlanta	0	0	0	0	0	0	1,000	0	0	0
	LA	0	0	0	0	0	0	1,000	0	0	0
	Unmet demand	0	0	0	0	0	0				

	Wipes	Ointment
Fixed cost, $	9,400,000	1,500,000
Production cost, $	45,000,000	10,300,000
Transportation cost, $	17,524,000	2,697,400
Total cost, $	86,421,400	

Figure 5: Solution of Q3-b with baseline transportation costs

		Northwest	Southwest	Upper Midwest	Lower Midwest	Northeast	Southeast	Capacity	Open (=1) or closed (=0)	Facility usage	Leftover capacity
Wipes	Chicago	500	700	900	800	1,000	600	5,000	1	4,500	500
	Princeton, NJ	0	0	0	0	0	0	2,000	0	0	0
	Atlanta	0	0	0	0	0	0	2,000	0	0	0
	LA	0	0	0	0	0	0	2,000	0	0	0
	Unmet Demand	0	0	0	0	0	0				
Ointment	Chicago	50	90	120	65	120	70	1,000	1	515	485
	Princeton, NJ	0	0	0	0	0	0	1,000	0	0	0
	Atlanta	0	0	0	0	0	0	1,000	0	0	0
	LA	0	0	0	0	0	0	1,000	0	0	0
	Unmet demand	0	0	0	0	0	0				

	Wipes	Ointment
Fixed cost, $	5,000,000	1,500,000
Production cost, $	45,000,000	10,300,000
Transportation cost, $	11,732,000	1,348,700
Total cost, $	74,880,700	

Figure 6: Solution of Q3-b with half transportation costs

		Northwest	Southwest	Upper Midwest	Lower Midwest	Northeast	Southeast	Capacity	Open (=1) or closed (=0)	Facility usage	Leftover capacity
Wipes	Chicago	0	0	900	800	0	0	5,000	1	1,700	3,300
	Princeton, NJ	0	0	0	0	0	0	2,000	0	0	0
	Atlanta	0	0	0	0	1,000	600	2,000	1	1,600	400
	LA	500	700	0	0	0	0	2,000	1	1,200	800
	Unmet Demand	0	0	0	0	0	0				
Ointment	Chicago	50	90	120	65	120	70	1,000	1	515	485
	Princeton, NJ	0	0	0	0	0	0	1,000	0	0	0
	Atlanta	0	0	0	0	0	0	1,000	0	0	0
	LA	0	0	0	0	0	0	1,000	0	0	0
	Unmet demand	0	0	0	0	0	0				

	Wipes	Ointment
Fixed cost, $	9,400,000	1,500,000
Production cost, $	45,000,000	10,300,000
Transportation cost, $	35,048,000	5,394,800
Total cost, $	106,642,800	

Figure 7: Solution of Q3-b with doubled transportation costs

Interestingly, although constructing a new facility incurs additional costs, the benefits in transportation savings are significantly more significant in the baseline case (Fig. 5) and the case with doubled transportation costs (Fig. 7). Therefore, building two additional plants for wipes in Atlanta and LA is unfolded as the best option in these cases.

However, if the transportation cost is reduced to half, maintaining and fully utilizing the existing facilities is the best strategy (Fig. 6).

(c)

In this scenario, the only difference from b. is that we now have the option to open or close the plants in Chicago. Thus, from the perspective of the optimization problem, Eq. (18) is no longer needed. The corresponding y variables should also be included as decision variables for the code implementation. The optimization results are shown in Fig.

8 to Fig. 10.

The solutions across all cases are different. Notably, Chicago is not selected as a facility location in both the baseline and half transportation cost scenarios.

Locating facilities for wipes in Atlanta and LA appears to be a robust strategy, as the optimal solutions for all cases include these locations.

Since the scales of fixed and transportation costs are similar for ointment, constructing a single facility and fully utilizing it is consistently the best strategy, which is also the case for Question 2.

		Northwest	Southwest	Upper Midwest	Lower Midwest	Northeast	Southeast	Capacity	Open (=1) or closed (=0)	Facility usage	Leftover capacity
Wipes	Chicago	0	0	0	0	0	0	5,000	0	0	0
	Princeton, NJ	0	0	900	0	1,000	0	2,000	1	1,900	100
	Atlanta	0	0	0	800	0	600	2,000	1	1,400	600
	LA	500	700	0	0	0	0	2,000	1	1,200	800
	Unmet Demand	0	0	0	0	0	0				
Ointment	Chicago	0	0	0	0	0	0	1,000	0	0	0
	Princeton, NJ	0	0	0	0	0	0	1,000	0	0	0
	Atlanta	0	0	0	0	0	0	1,000	0	0	0
	LA	50	90	120	65	120	70	1,000	1	515	485
	Unmet demand	0	0	0	0	0	0				

	Wipes	Ointment
Fixed cost, $	6,600,000	1,500,000
Production cost, $	45,000,000	10,300,000
Transportation cost, $	19,068,000	2,986,800
Total cost, $	85,454,800	

Figure 8: Solution of Q3-c with baseline transportation costs

		Northwest	Southwest	Upper Midwest	Lower Midwest	Northeast	Southeast	Capacity	Open (=1) or closed (=0)	Facility usage	Leftover capacity
Wipes	Chicago	0	0	0	0	0	0	5,000	0	0	0
	Princeton, NJ	0	0	900	0	1,000	0	2,000	1	1,900	100
	Atlanta	0	0	0	800	0	600	2,000	1	1,400	600
	LA	500	700	0	0	0	0	2,000	1	1,200	800
	Unmet Demand	0	0	0	0	0	0				
Ointment	Chicago	0	0	0	0	0	0	1,000	0	0	0
	Princeton, NJ	0	0	0	0	0	0	1,000	0	0	0
	Atlanta	50	90	120	65	120	70	1,000	1	515	485
	LA	0	0	0	0	0	0	1,000	0	0	0
	Unmet demand	0	0	0	0	0	0				

	Wipes	Ointment
Fixed cost, $	6,600,000	1,500,000
Production cost, $	45,000,000	10,300,000
Transportation cost, $	9,534,000	1,317,200
Total cost, $	74,251,200	

Figure 9: Solution of Q3-c with half transportation costs

		Northwest	Southwest	Upper Midwest	Lower Midwest	Northeast	Southeast	Capacity	Open (=1) or closed (=0)	Facility usage	Leftover capacity
Wipes	Chicago	0	0	900	800	0	0	5,000	1	1,700	3,300
	Princeton, NJ	0	0	0	0	0	0	2,000	0	0	0
	Atlanta	0	0	0	0	1,000	600	2,000	1	1,600	400
	LA	500	700	0	0	0	0	2,000	1	1,200	800
	Unmet Demand	0	0	0	0	0	0				
Ointment	Chicago	0	0	0	0	0	0	1,000	0	0	0
	Princeton, NJ	0	0	0	0	0	0	1,000	0	0	0
	Atlanta	50	90	120	65	120	70	1,000	1	515	485
	LA	0	0	0	0	0	0	1,000	0	0	0
	Unmet demand	0	0	0	0	0	0				

	Wipes	Ointment
Fixed cost, $	9,400,000	1,500,000
Production cost, $	45,000,000	10,300,000
Transportation cost, $	35,048,000	5,268,800
Total cost, $	106,516,800	

Figure 10: Solution of Q3-c with doubled transportation costs

References

[1] Chopra, S., *Supply Chain Management: Strategy, Planning and Operation*, 7th ed., Pearson Education, London, United Kingdom, 2019, Chap. 3.