#I printed line numbers so that if something is wrong in printed page, one can check xls document faster.

IE 460 - HWK 4

The table below shows parameters.

Parameter	Value	Unit	Notation
Daily demand in Ankara	50	piece/day	D_A
Daily demand in Eskisehir	20	piece/day	D_E
Holding cost	4	TL/piece/day	H
Istanbul-Ankara	500	km	IstAnk
Istanbul-Eskisehir	450	km	IstEsk
Eskisehir-Ankara	200	km	EskAnk
Truck Capacity	100	piece	TruckCap
Truck cost	0.8	TL/km	TruckCost
Material handling cost at RDC	3	TL/piece	h_RDC
Material handling cost with milkrun	1	TL/piece	h_Milkrun

Alternative 1	RDC in Eskisehir and Ankara
Alternative 2	Daily direct shipment with milkrun strategy

Assumption: Truck costs are linear
Assumption: Milkrun strategy cannot be used in RDC Operations
Assumption: The number of trucks owned by Arcelik is unlimited.

PART A (a) (i)

Observation 1: Truck capacity is more than weekly demand, so it is not optimal send two trucks in a day and hold one truckload of item as inventory.
Observation 2: We have additional assumption that time between two consecutive shipments are days, therefore, number of items in a truck should be an integer multiple of daily demand.

Cost Factors are: Inventory holding costs (Cycle inventory only)
Transportation cost
Handling cost

Alternative 1

Let Q_A and Q_E be optimal order quantities for Ankara and Eskisehir.
Q_A can take values in {50,100}
Q_E can take values in {20,40,60,80,100}
Define Clength as Q_A/D_A or Q_E/D_E, the length of cycle (in days) for a given order level.

Alternative 1 - Ankara

Cost Component	Value	Unit	Explanation
Case 1: Q_A =	50		
Holding cost=	0	TL/day	(Q-D_A) *H / Clength
Transportation cost=	800	TL/day	(IstanbulAnkara km*2*Truckcost)/Clength
Handling Cost=	150	TL/day	(Q*handlingCost)/Clength
Total Cost=	950	TL/day	Total

Case 2: Q_A =	100		
Holding cost=	100	TL/day	(Q-D_A)*H+(Q-2*D_A)*H/Clength
Transportation cost=	400	TL/day	(IstanbulAnkara km*2*Truckcost)/Clength
Handling Cost=	150	TL/day	(Q*handlingCost)/Clength
Total Cost=	**650**	**TL/day**	**Total**

Alternative 1 - Eskisehir

Case 1: Q_E =	20		
Holding cost=	0	TL/day	(Q-D_A)/Clength
Transportation cost=	720	TL/day	(IstEsk km*2*Truckcost)/Clength
Handling Cost=	60	TL/day	(Q*handlingCost)/Clength
Total Cost=	780	TL/day	Total

Case 2: Q_E =	40		
Holding cost=	40	TL/day	(Q-D_A)+(Q-2*D_A)/Clength
Transportation cost=	360	TL/day	(IstEsk km*2*Truckcost)/Clength
Handling Cost=	60	TL/day	(Q*handlingCost)/Clength
Total Cost=	460	TL/day	Total

Case 3: Q_E =	60		
Holding cost=	80	TL/day	(Q-D_A)+(Q-2*D_A)+(Q-3*D_A)/Clength
Transportation cost=	240	TL/day	(IstanbulEskisehir km*2*Truckcost)/Clength
Handling Cost=	60	TL/day	(Q*handlingCost)/Clength
Total Cost=	380	TL/day	Total

Case 4: Q_E =	80		
Holding cost=	120	TL/day	(Q-D_A)+(Q-2*D_A)+(Q-3*D_A) + (Q-4*D_A)/Clength
Transportation cost=	180	TL/day	(IstanbulEskisehir km*2*Truckcost)/Clength
Handling Cost=	60	TL/day	(Q*handlingCost)/Clength
Total Cost=	**360**	**TL/day**	**Total**

Case 5: Q_E =	100		
Holding cost=	160	TL/day	
Transportation cost=	144	TL/day	(IstanbulEskisehir km*2*Truckcost)/Clength
Handling Cost=	60	TL/day	(Q*handlingCost)/Clength
Total Cost=	364	TL/day	Total

Alternative 2 - Milkrun

Cost components are: Transportation Cost + Handling Cost

Observaton: Number of items in a truck does not change over time because the shipments are daily.

There is only one case under this assumption, the sum of daily demand in Eskisehir and Ankara.

Q=	70		(50 for Ankara, 20 for eskisehir)
Transportation Cost=	920	TL/day	(IstAnk+EskAnk+IstEsk)*TruckCost
Handling Cost=	70	TL/day	Q*h_Milkrun
Total Cost=	990	TL/day	

Total cost of alternative 1=	1010	TL/day	360+650
Total cost of alternative 2=	990	TL/day	

We can select alternative 2 (milk run strategy), but further analyses can be:

- Analyzing RDC operations with milkrun strategy.
- Analyzing milkrun strategy when amount of item in a truck can be changed over time in a cycle. (Explained later in)

PART A (a) (ii)

Now, we can use EOQ approach.

Cost Components are: Transportation + Holding + Handling Costs

However, tradeoff is between transportation and holding costs, since handling cost per day is fixed.

Alternative 1 - Ankara

Transportation cost =	800	TL	(IstAnk+IstAnk)*TruckCost
Q_A =	141.4214	piece	SQRT((2*TransportCost*D_A)/H)

141>100, then using one full truck is the best decision because truck capacity is more than daily demand
and sending two trucks in a day causes unnecessary inventory holding cost (by Chopra p. 290)

Trans + Holding Cost with full truck	600	TL/day	TransportCost*D_A/TruckCap + H*TruckCap/2
Handling Cost=	150	TL/day	D_A*h_RDC
Total Cost =	**750**	TL/day	

Alternative 1 - Eskisehir

Transportation cost =	720	TL	IstEsk*2*TruckCost
Q_E=	84.85281	piece	SQRT(2*TransportCost*D_E/H)
Trans + Holding Cost (Q_E)=	339.4113	TL/day	TransportCost*D_E/Q_E + H*Q_E/2
Handling cost =	60	TL/day	D_E*h_RDC
Total Cost =	**399.4113**	**TL/day**	

Total Cost of Alternative 1= **1149.411**

Alternative 2 - Milkrun

Transportation Cost=	920	TL	(IstAnk+IstEsk+EskAnk)*TruckCost
Q =	179.4436	piece	SQRT(2*TransCost*(D_A+D_E)/H)

Then using one full truck is the best decision. (by Chopra p. 290)

Trans + Holding w/ Full Truck =	844	TL/day	TransC*(D_A+D_E)/100 + H*100/2
Handling Cost =	70	TL/day	(D_A+D_E) * h_Milkrun
Total cost =	**914**	**TL/day**	

Milkrun strategy gives lower total cost.

PART A (a) (iii)

We can change the amount of items sent per day over time and create a cycle. For instance, four days can be the cycle length and the amount of items in each day can be 50+40, 50+40, 100, 0 (no shipment in the fourth day). It becomes a combinatorial problem. Computations are left to you, since everyone comes up with a different improvement method.

PART A (b) (i)

d

Term	Value	Unit	Notation
Std. dev. of demand in Ankara	15	piece/day	Sigma_A
Std. dev. of demand in Eskisehir	5	piece/day	Sigma_E
Transportation lead time	1	day	L
Fill rate	0.95		fr
# of days between shipments			k

Cost factors are: Inventory holding Costs (Cycle + Safety Inventory)
Transportation Costs
Handling Costs

General formula for RDC Operations:

Let Q be order size, D be daily demand. For each k in {1,2,…, 100/D}, we need to calculate the followings:

Q= k * D

Transportation cost (Daily) = (km between two cities * 2 * TruckCost)/k

Cycle Inv. Holding Cost (daily) = (k*D - D + k*D - 2*D + … + k*D-k*D)*H/k
= D * (k-1 + k-2 + … + 1 + 0) * H/k
= D * (k-1) * k * H/ (2*k)
= D * (k-1) * H/ 2

Handling Cost (daily) = D * h_RDC

Safey Stock : There are two approaches listed below, I will follow the second approach since it is faster to do.

<u>Approach 1 : Chopra Equation. 12.10</u>

Step 1 : Find target expected shortage per cycle: ESC = (1-fr)*Q = (1-fr)*k*D

Step 2 : Find required safety stock values by trying different values of ss in equation 12.10 (Chopra):

Approach 2 : Nahmias page 270 and Table A-4 (when demand is normally distributed)
Step 1: Find target expected shortage per cycle : ESC = (1-fr)*Q = (1-fr)*k*D
Step 2: Find review + lead time standard deviation of demand = sqrt(k+L)*Sigma_A (or sqrt(k+L) * Sigma_E)
Step 3: Find L(z) value : L(z) = ESC / (sqrt(k+L)*Sigma_A) or L(z) = ESC / (sqrt(k+L)*Sigma_E)
Step 4: Find z value using Table A-4
Step 5: Find safety stock : ss = z * lead time std. dev.
Step 6: Cost of safety stock (daily) = ss * H

PART A (b) (ii)

I will not write the formulas next to numbers since I wrote a general formula in Part A (b) (i)

Alternative 1 - Ankara

Case 1: k =	1		
Q=	50	Piece	
Transpotation cost (daily) =	800	TL/day	
Holding Cost (daily) =	0	TL/day	
Handling Cost (daily) =	150	TL/day	
ESC =	2.5	Piece/day	
L(z) =	0.117851		
z=	0.81		(from table)
ss =	17.18269		
Safety stock Cost (daily) =	68.73078		
Total Cost =	1018.731		

Case 1: k =	2		
Q=	100	Piece	
Transpotation cost (daily) =	400	TL/day	
Holding Cost (daily) =	100	TL/day	
Handling Cost (daily) =	150	TL/day	
ESC =	5	Piece/day	
L(z) =	0.19245		
z=	0.51		(from table)
ss =	13.25019		
Safety Stock Cost (daily) =	53.00075		
Total Cost =	**703.0008**		

The lowest cost for Ankara is obtained when k = 2.

Alternative 2 - Eskisehir

Case 1: k = 1

Q=	20	Piece	
Transpotation cost (daily) =	720	TL/day	
Holding Cost (daily) =	0	TL/day	
Handling Cost (daily) =	60	TL/day	
ESC =	1	Piece/day	
L(z) =	0.141421		
z=	0.7		(from table)
ss =	4.949747		
Safety stock Cost (daily) =	19.79899		
Total Cost =	799.799		

Case 2: k = 2

Q=	40	Piece	
Transpotation cost (daily) =	360	TL/day	
Holding Cost (daily) =	40	TL/day	
Handling Cost (daily) =	60	TL/day	
ESC =	2	Piece/day	
L(z) =	0.23094		
z=	0.4		(from table)
ss =	3.464102		
Safety stock Cost (daily) =	13.85641		
Total Cost =	473.8564		

Case 3: k = 3

Q=	60	Piece	
Transpotation cost (daily) =	240	TL/day	
Holding Cost (daily) =	80	TL/day	
Handling Cost (daily) =	60	TL/day	
ESC =	3	Piece/day	
L(z) =	0.3		
z=	0.22		(from table)
ss =	2.2		
Safety stock Cost (daily) =	8.8		
Total Cost =	388.8		

Case 4: k =	4		
Q=	80	Piece	
Transpotation cost (daily) =	180	TL/day	
Holding Cost (daily) =	120	TL/day	
Handling Cost (daily) =	60	TL/day	
ESC =	4	Piece/day	
L(z) =	0.357771		
z=	0.08		(from table)
ss =	0.894427		
Safety stock Cost (daily) =	3.577709		
Total Cost =	**363.5777**		

Case 5: k =	5		
Q=	100	Piece	
Transpotation cost (daily) =	144	TL/day	
Holding Cost (daily) =	160	TL/day	
Handling Cost (daily) =	60	TL/day	
ESC =	5	Piece/day	
L(z) =	0.408248		
z=	0		(from table)
ss =	0		
Safety stock Cost (daily) =	0		
Total Cost =	364		

k = 4 or 5 gives very similar results for Eskisehir. Both can be chosen based on other criterias (e.g. lifetime of truck). I chose k = 4 here.
Here, there is a very counter-intuitive result. When the review period (k) gets larger, the amount of safety inventory gets lower. I believe that it is due to increasing Expected Stockout per Cycle. To describe this interesting result, we need to find the relationship between safety stock and review period analytically.

Part B - 1

Currently, milk-run strategy is a better option. Therefore, lets lower the handling cost of RDC until two alternatives yield same total cost. For this, I will use Binary Search Algorithm in CS 114: First examine the middle element of the possible values of handling costs, if it matches the target, search is over, if not only half of the values should be examined. Select middle element until the search is over.

When handling cost = 2.72, we have

Total cost of alternative 1=	990.4	TL/day	360+650
Total cost of alternative 2=	990	TL/day	

Therefore, when handling cost for alternative 1 is larger than 2.72, milk run strategy yields lower total cost.

Part B - 2

Currently, milk run strategy is a better option. Therefore, lets lower the holding cost until two alternatives yield the same cost.
I will use the same methodology in Part B-1

The interesting result is: when holding is lowered, both alternative 1 and 2 yields lower costs. Therefore, the break-even point is much lower than I expected, when H = 0.53,

Total Cost of Alternative 1=	740.4476	
Total cost of Alternative 2 =	740.5	TL/day

Part B - 3

I will do it for Part A (a) (ii) for simplicity. Currently, milk-run strategy is the better option. We should increase the cost per 100 km so that the effect of holding cost in Alternative 1 diminishes.

Current Picture:

<u>Alternative 1 - Ankara</u>

Transportation cost =	800	TL	(IstAnk+IstAnk)*TruckCost
Q_A =	141.4214	piece	SQRT((2*TransportCost*D_A)/H)

141>100, then using one full truck is the best decision because truck capacity is more than daily demand and sending two trucks in a day causes unnecessary inventory holding cost (by Chopra p. 290)

Trans + Holding Cost with full truck	600	TL/day	TransportCost*D_A/TruckCap + H*TruckCap/2
Handling Cost=	150	TL/day	D_A*h_RDC
Total Cost =	**750**	TL/day	

<u>Alternative 1 - Eskisehir</u>

Transportation cost =	720	TL	IstEsk*2*TruckCost
Q_E=	84.85281	piece	SQRT(2*TransportCost*D_E/H)
Trans + Holding Cost (Q_E)=	339.4113	TL/day	TransportCost*D_E/Q_E + H*Q_E/2
Handling cost =	60	TL/day	D_E*h_RDC
Total Cost =	**399.4113**	**TL/day**	

Total Cost of Alternative 1= 1149.411

<u>Alternative 2 - Milkrun</u>

Transportation Cost=	920	TL	(IstAnk+IstEsk+EskAnk)*TruckCost
Q =	179.4436	piece	SQRT(2*TransCost*(D_A+D_E)/H)

Then using one full truck is the best decision. (by Chopra p. 290)

Trans + Holding w/ Full Truck =	844	TL/day	TransC*(D_A+D_E)/100 + H*100/2
Handling Cost =	70	TL/day	(D_A+D_E) * h_Milkrun
Total cost =	**914**	**TL/day**	

When Truck capacity is 135 and cost per 100 km is 397 :

Alternative 1 - Ankara

Transportation cost =	3970	TL	(IstAnk+IstAnk)*TruckCost
Q_A =	315.0397	piece	SQRT((2*TransportCost*D_A)/H)
141>100, then using one full truck is the best decision because truck capacity is more than daily demand and sending two trucks in a day causes unnecessary inventory holding cost (by Chopra p. 290)			
Trans + Holding Cost with full truck	1740.37	TL/day	TransportCost*D_A/TruckCap + H*TruckCap/2
Handling Cost=	150	TL/day	D_A*h_RDC
Total Cost =	**1890.37**	TL/day	

Alternative 1 - Eskisehir

Transportation cost =	3573	TL	IstEsk*2*TruckCost
Q_E=	189.0238	piece	SQRT(2*TransportCost*D_E/H)
Trans + Holding Cost (Q_E)=	756.0952	TL/day	TransportCost*D_E/Q_E + H*Q_E/2
Handling cost =	60	TL/day	D_E*h_RDC
Total Cost =	**816.0952**	**TL/day**	

Total Cost of Alternative 1= 2706.466

Alternative 2 - Milkrun

Transportation Cost=	4565.5	TL	(IstAnk+IstEsk+EskAnk)*TruckCost
Q =	399.7405	piece	SQRT(2*TransCost*(D_A+D_E)/H)
Then using one full truck is the best decision. (by Chopra p. 290)			
Trans + Holding w/ Full Truck =	2637.296	TL/day	TransC*(D_A+D_E)/100 + H*100/2
Handling Cost =	70	TL/day	(D_A+D_E) * h_Milkrun
Total cost =	**2707.296**	**TL/day**	

Part B - 4

This analysis is left to you, you need to check the z values from table A-4 for each different service levels. Fortunately, you can program the standardized loss function in excel. Please see Nahmias p. 278 for the formulation.

Part C

Question: What can you say about the comparison of results for periodic review and continuous review systems? Why do we have differences? Which one should be better?

Answer: Continous review systems is expected to give better objective function value because continous review system includes all the possible review points that any periodic review system can have. More formally, the review points in any periodic system is a subset of the review points in a continuous review system. Therefore, the feasible region (of cycle length) of continuous review system is larger.

More points from Chopra:

- Periodic review replenishment policies require more safety inventory than continous review policies for the same lead time and level of product availability.

Question: Which one is more likely to be implemented?

Answer: From different parts of Chopra:

- Periodic review policies are simpler to implement because it does not the capability of monitoring inventory continuously.
- Suppliers may also prefer them because they result in replenishment orders placed at regular intervals.
- However, the broad use of bar codes and POS systems as well as the emergence of RFID technology, continuous tracking of all inventories is much more commonplace today than it was a decade ago.
- In some instances, companies partition their products based on their value. High-value product are managed using continious review policies, and low-value product are managed using periodic review policies.

My comment from what I learnt from Chopra's comments:

- There is trade-off between the cost of deploying the technology for continous tracking of inventory and the cost of objective function value.