CASE STUDY REPORT

MANAGING INVENTORIES AT ALKO, INC.

Project Report

ISEN 615 Production and Inventory Control

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Submitted By –

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1. Executive Summary

In this case study, we analysed the current distribution system of Alco Inc. and determined operating costs. We also analysed the expected costs resulting from operationalizing the task force recommendation of setting up a National Distribution Centre as a function of the correlation in demand between each pair of regions. We also considered other options and evaluated them to put forth our recommendations, based on a reasonable set of assumptions.

The system under examination has been analysed on the following criteria:

- The variation of correlation coefficient
- Risk Pooling
- Centralized vs. Decentralized Systems

The following factors affect the inventory cost:

- Demand Characteristics
- Lead Time and transit time
- Cycle Time
- Number of Products
- Service level
- Cost Structure (Holding, Transportation, Setup etc.)

2. The Current Distribution System & its Costs (Answer to Question 1)

What is the annual inventory and distribution cost of the current distribution system?

The current distribution system is represented pictorially in Fig. 1.

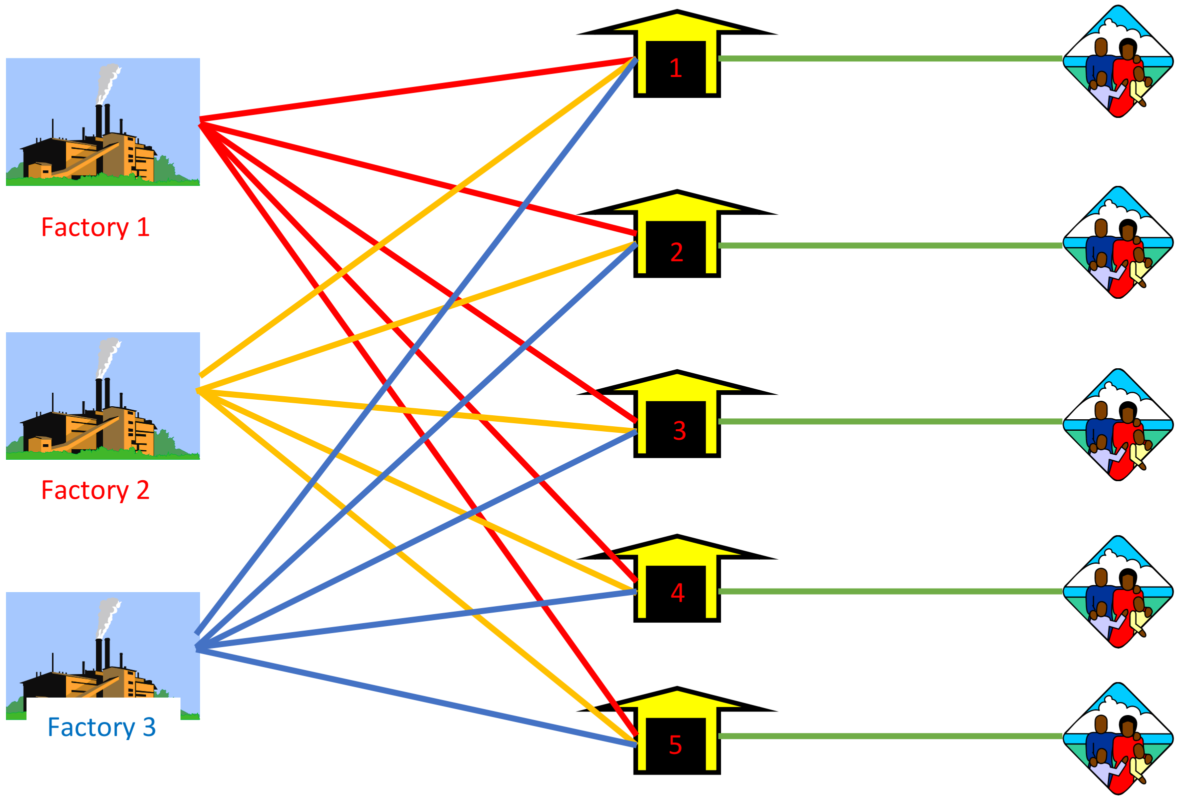
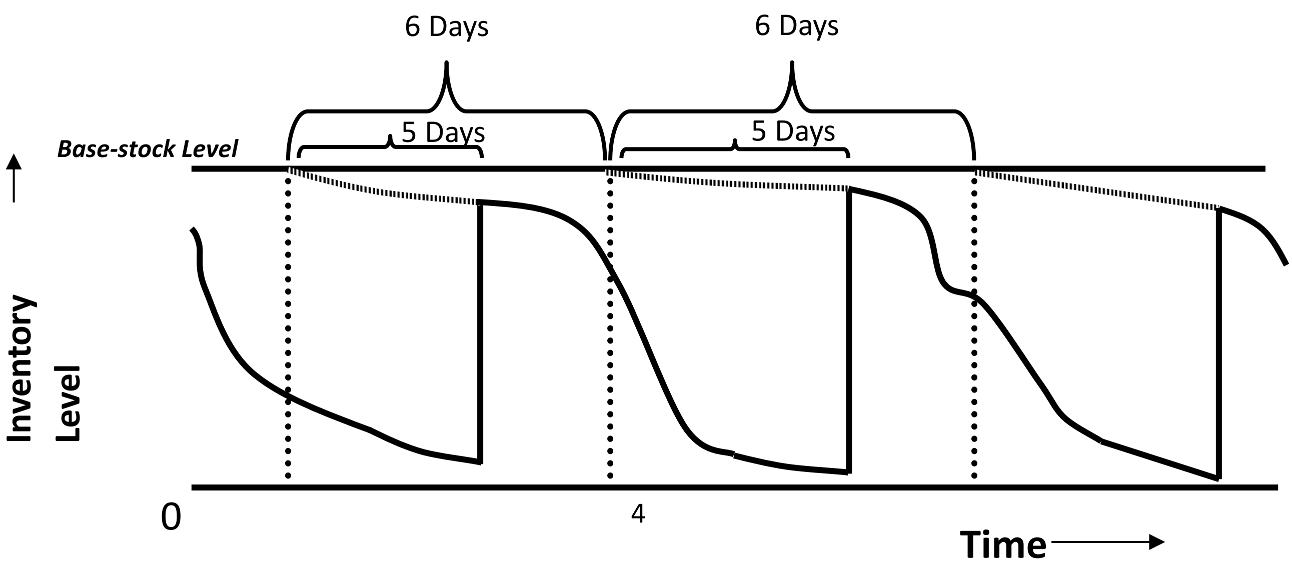


Figure 1 : Supply Chain overview of Alco Inc.

2.1 The Current System:

As the Inventory is replenished every 6 days (Cycle time) and each shipment takes 5 days to arrive (Lead time), the variation of Inventory level for each product at the Distribution Centres can be represented by the following graph:



The distribution of daily product demands for each of the warehouses have been provided to us:

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1 Mean	35.48	22.61	17.66	11.81	3.36
Part 1 Std Dev	6.98	6.48	5.26	3.48	4.49
Part 1 Variance	48.7204	41.9904	27.6676	12.1104	20.1601
Part 3 Mean	2.48	4.15	6.15	6.16	7.49
Part 3 Std Dev	3.16	6.2	6.39	6.76	3.56
Part 3 Variance	9.9856	38.44	40.8321	45.6976	12.6736
Part 7 Mean	0.48	0.73	0.8	1.94	2.54
Part 7 Std Dev	1.98	1.42	2.39	3.76	3.98
Part 7 Variance	3.9204	2.0164	5.7121	14.1376	15.8404

Table 1 : Demand Distribution

2.2 Notations & Given Information:

- Q_{avg} = average daily demand of the part
- μ_{part} = standard deviation of daily demand for the part
- σ_{part} = standard deviation of daily demand for the part
- L = replenishment lead time in days
- T = cycle time in days
- h = holding cost of one unit for one day
- CSL = service level
- SS = safety stock

Given :

Inbound Transportation Cost	TL	$	0.09	per unit
Outbound Transportation Cost	LTL	$	0.10	per unit
Total Transportation Cost		**$**	**0.19**	per unit
Annual Holding Cost	h	$	0.15	per unit per day or $ 54.75 per year
Reorder Interval	T		6	days
Replenishment Lead Time	L		5	days
Transit Time for DCs			**4**	**Days**

We have assumed that actual transportation time is 4 days out of 5 (between factory and DC) and the one day is required for paperwork.

2.3 Annual Inventory Holding & Transportation Cost

The holding cost would be the overall cost of the following:

a) Cost of maintaining the safety stock levels inside the warehouse throughout the year

b) Cost of maintaining the cycle inventory, and

c) Holding cost incurred during all transits over a year

Transportation Cost of a unit per day based on average daily demand is given by the following :

Total Transportation Cost = Demand per cycle*No. of cycles per year*Unit cost

It is given that Of the 100 products that Alko sold, 10 were of type High (Part 1), 20 of type Medium (Part 3), and 70 of type Low (Part 7).

Total Cost per product type = (Holding cost + Transportation cost) *No. of items of the particular product type.

Detailed calculations are shown in **Annexure A.**

Total Annual Inventory and Distribution Costs for Current System with five DC's by part, region and total is as below :

	Region 1	Region 2	Region 3	Region 4	Region 5	Products with Similar Volume	Total Cost
Part 1	$ 18,143	$ 12,169	$ 9,564	$ 6,385	$ 2,862	10	$ 491,222
Part 3	$ 2,066	$ 3,730	$ 4,692	$ 4,807	$ 4,453	20	$ 394,977
Part 7	$ 809	$ 755	$ 1,076	$ 2,001	$ 2,338	70	$ 488,497
				Total Cost of Scenario 1			**$ 1,374,696**

Total Annual Cost for current system - **$ 1,374,696.**

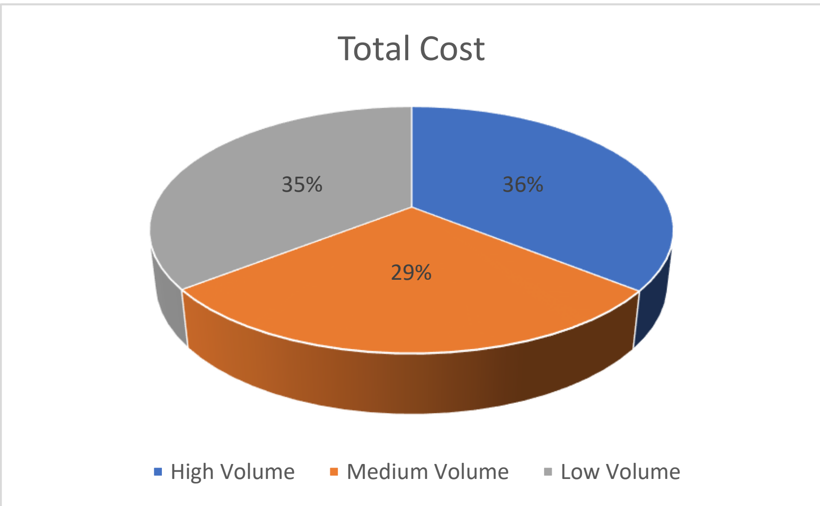


Figure 3 : Distribution of Total Cost

3. Setting Up an NDC & its Costs (Answer to Question 2)

What are the savings that would result from following the task force recommendation and setting up the NDC? Evaluate the savings as the correlation coefficient of demand in any pair of regions varies from 0 to 0.5 to 1.0. Do you recommend setting up an NDC?

The proposed distribution system is represented pictorially in Fig. 2.

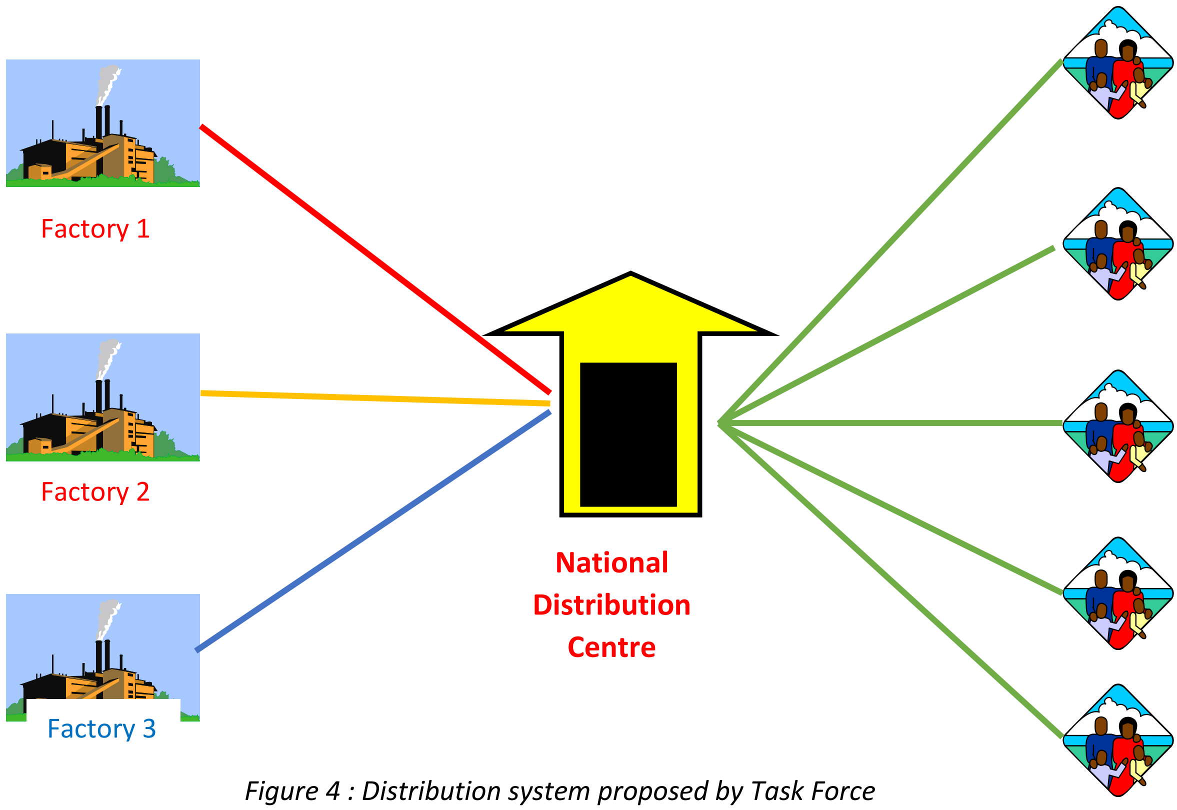


Figure 4 : Distribution system proposed by Task Force

Since the NDC is located closer to the factory, we assume that the transit time is reduced from 4 days (out of 5 days lead time) to 3 days (out of 5 days lead time). If the NDC is even closer, there will be further savings due to reduction in in-transit inventory.

Detailed Cost Computation is shown in Annexure B.

3.1 Summary of savings for different correlation coefficients

Scenario	Safety Stock Cost	In-Transit Inventory Cost	Transportation Cost	Total	Saving
Current	\$518,331.16	\$414,369.90	\$131,217.14	\$1,374,695.62	
NDC with rho = 0	\$244,134.98	\$310,777.43	\$200,278.79	\$1,065,968.62	**\$308,727.00**
NDC with rho = 0.5	\$405,141.34	\$310,777.43	\$200,278.79	\$1,226,974.97	**\$147,720.64**
NDC with rho = 1	\$518,331.16	\$310,777.43	\$200,278.79	\$1,340,164.79	**\$34,530.83**

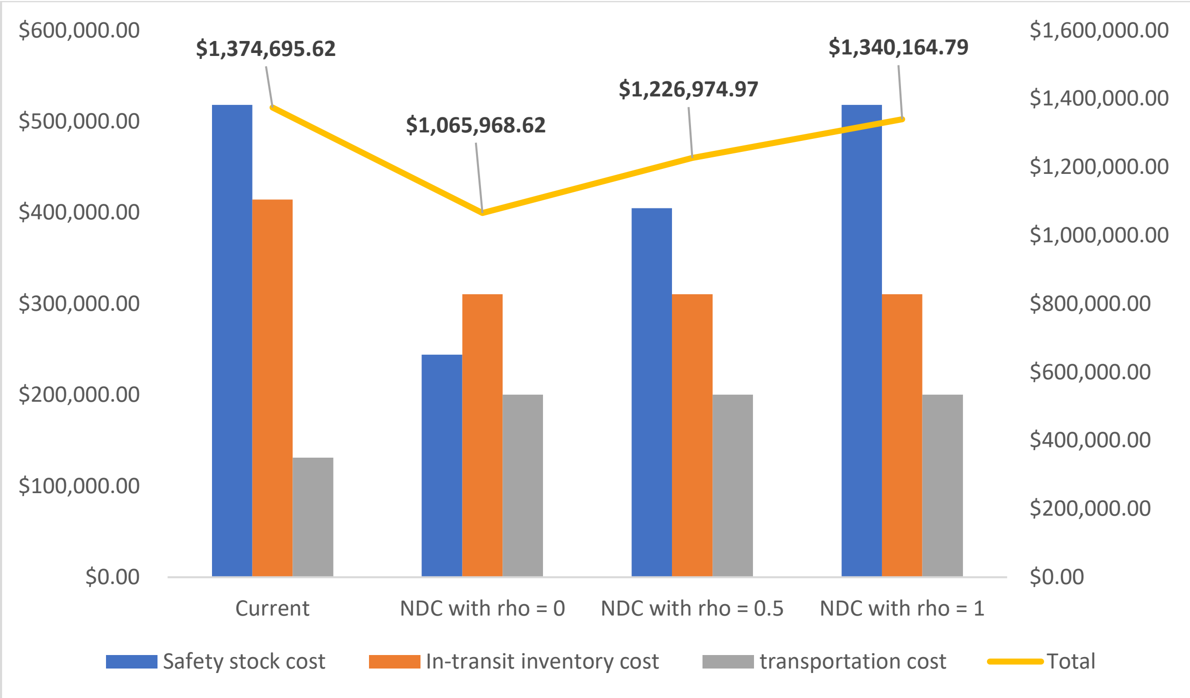


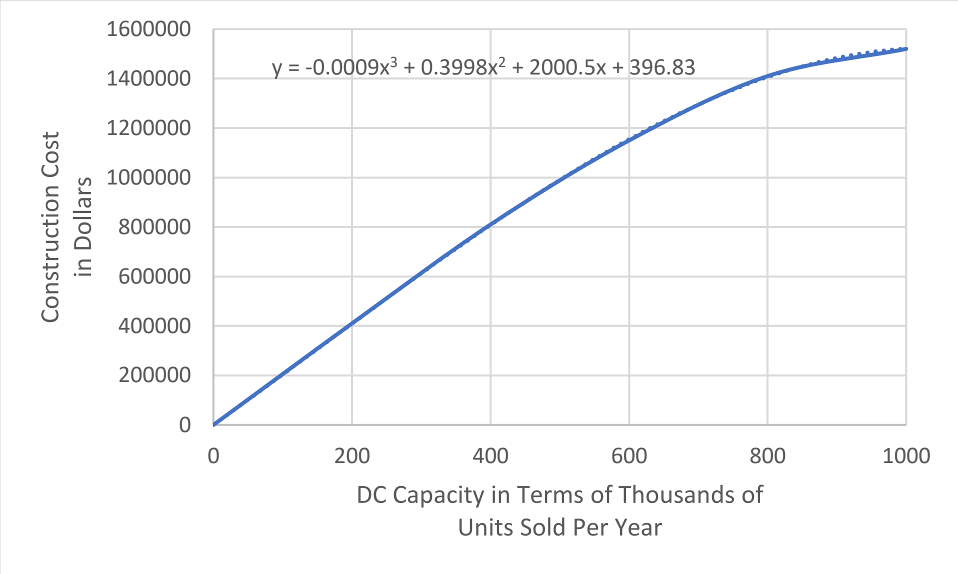
Figure 5 : Comparison of Costs as a function of Correlation Coefficient

Inferences :

1. We see that when demand distributions across regions are independent, the best solution is obtained with the lowest total cost.
2. As we move from multiple DC's to an NDC which is closer to the factories, the in-transit inventory reduces, thereby reducing its carrying cost. It remains constant regardless of the correlation coefficient.
3. The reduction in in-transit inventory cost due to setting up of an NDC is partially offset due to an increase in per unit outbound transportation cost, presumably due to an increased distance from the demand centres. Transportation cost is also independent of correlation coefficient.
4. The safety stock depends on the covariance between regions, and as the correlation coefficient increases, the safety stock required increases. For rho = 1, the effect of pooling vanishes and there is no savings in safety stock costs.
5. Risk pooling by setting up an NDC also leads to a reduction in the variance of the demand, thereby leading to a reduction in Safety Stock and its holding cost.

3.2 Cost of Construction of National Distribution Centre

We are given :



We fit a third degree polynomial to the data and obtain the equation as :

$$y = -0.0009x^3 + 0.3998x^2 + 2000.5x + 396.83$$

Since Construction Cost is a function of Annual Sales, we compute the total demand across all parts : (Daily Demand * 365 * No. of Products of this type) = **690,616.5**

From this value of the total demand, we arrive at Construction Cost of NDC : **$ 1,276,208.91**

3.3 Cash Flow & Payback Period

We assume that the NDC Construction Amount is paid in **three equal annual instalments** with the first instalment in year 0.

We assume a lending rate of 12%.

Profit in operational efficiency is only realized after the break-even / payback period, which is listed below:

Correlation Coefficient ρ	**0**	**0.5**	**1**
break-even / payback period	**4 years**	**8.5 years**	**36 years**

3.4 Recommendation

If the correlation coefficient between regions is determined to be 0 or 0.5, **we recommend setting up an NDC** since the investment will pay off in a reasonable timeframe (4 or 8.5 years). We do not recommend setting up an NDC when the correlation coefficient is 1.

4. Assumptions Made (Answer to Question 3)

Discuss the assumptions you employ regarding the distribution of demands for the products, and their validity with respect to the analysis you apply.

Several assumptions/notes were made regarding the distribution of demands of the parts at different regions. Below are all the assumptions made about various aspects of the case.

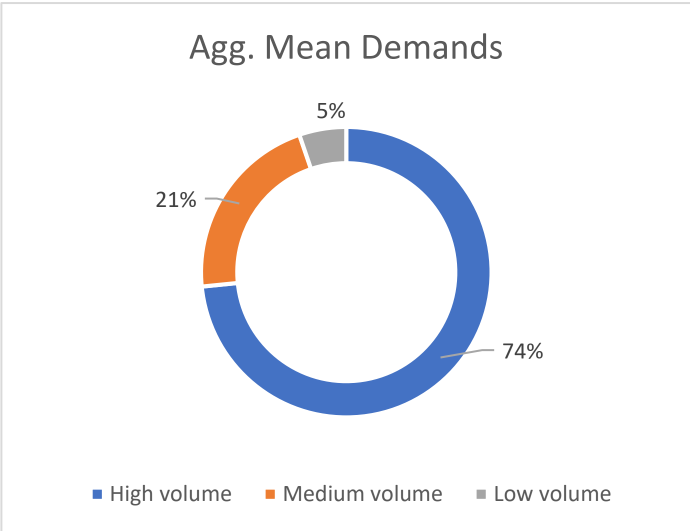
1. Whatever the mean demand is at the individual DC's, is what is being ordered at the factory. This is apart from the obvious and a note that there is no Bullwhip effect of the demand being considered, as whatever is being ordered at the DC's is directly shipped to customers.
2. The entire system is a periodic review order system where each period, the order up to quantity is Q = μ_{part} *T and depending on the variability of the demand of the parts in the regions, the difference of the demands at that point and Q is what is ordered.
3. Since the there is no information about the distance of inbound and outbound transportation and since the mean units' inflow = outflow for each of the parts in their regions (from assumption 1) for the individual DC's and NDC, the sum of the inbound and outbound costs per unit was taken to find total transportation costs, costs are independent of distance.
4. Since NDC is closer to factory, the time for inbound transportation of goods is assumed to be lesser, i.e at 3 days compared to 4 days for the individual DC's. However, since the quantity stored at the NDC is more, ancillary activities (paperwork/packaging) takes two days, which is why the replenishment lead time is still taken to be 5 days.
5. It is assumed that the time taken to construct a warehouse is 3 years, and the investments made for it begin from the 0^{th} year (right now) till 2^{nd} year. Investments of $1.2 Million is made in 3 equal instalments, and the interest rate of 12% compounded annually for that was considered each year, which comes to around $0.53 Million each year. At the end of the 3^{rd} year is when the NDC will be fully functioning and the DC's are then salvaged for $50,000 each.
6. The distribution of the demands among the regions are correlated and are normally distributed. This is an important assumption as the safety stock calculation would then change since $\sigma_{aggregated}$ would change.
7. There is no correlation between the types of parts i.e. between high and low value products as that would over complicate things and it would be difficult to find that correlation for each region (DC's) as well as when it is aggregated at NDC.
8. When finding in transit inventory holding costs for both at DC's and NDC, the total inventory in transit for a cycle was calculated and was then multiplied with the holding cost, which is for the number of days it was in transit (4 days for DC, 3 days for NDC), i.e C_h = Number of days inventory was in transit * holding cost/unit/day . This quantity is then multiplied by number of cycles in a year to obtain yearly in transit inbound inventory holding cost. Outbound in transit inventory holding cost is beyond the scope of the study.

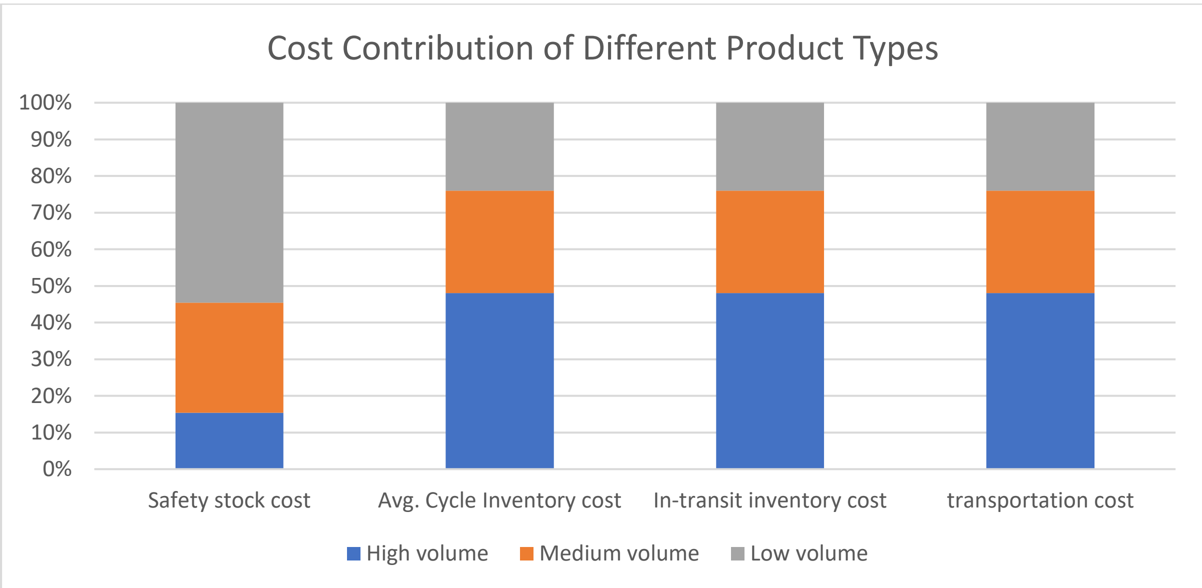
5. Evaluation of Other Options & Recommendation (Answer to Question 4)

Suggest other options that Gary Fisher should consider. Evaluate each option and recommend a distribution system for Alko that would be most profitable. How dependent is your recommendation on the correlation coefficient of demand across different regions?

We take a look at the data to identify the best options.

The low volume products consist of only 5 % of total demands of Alko Inc., but it contributes to more than 50 % of the safety stock holding inventory cost. Similarly, the safety stock cost for medium volume products is also larger than that of the high volume products. This is because of high co-efficient of variance for low and medium volume products, i.e. the variance in demand is large. To reduce these safety stock cost, it is required to pool the low and medium volume products.





However, the per unit transportation cost (inbound + outbound) increases from \$0.19 to \$0.29. Therefore, the pooling of products through NDC is only justified if the reduction in safety stock cost is more than the increase in transportation costs.

Since the transportation cost for Alko Inc. is based only on the number of units shipped, the increase in transportation cost for high volume products is significant when pooled from

NDC, because of the large demands. Now, the high volume products have low co-efficient of variance and therefore, pooling does not reduce the variance in demand. Hence the reduction in safety stock cost is lower than the increase in transportation cost. So, we should try to keep the ***DCs open to reduce the transportation cost of high volume products and utilize the NDC to reduce the safety stock costs for medium and low volume products.***

Current Scenario | ***$1,374,695.62***

	ρ	Only NDC	NDC & DCs: Pooling medium & low	NDC & DCs: Pooling high
Costs	**0**	$1,065,968.62	$1,125,619.65	$1,315,044.59
	0.5	$1,226,974.97	$1,261,241.91	$1,340,428.68
	1	$1,340,164.79	$1,356,757.69	$1,358,102.72
Savings	**0**	$308,727	$249,076	$59,651
	0.5	$147,721	$113,454	$34,267
	1	$34,531	$17,938	$16,593
NPV of [-Investment + Salvage]	**any ρ**	($1,251,408.91)	($815,352.23)	($756,465.85)
Breakeven / Payback (No. of years)	**0**	-4.05	-3.27	-12.68
	0.5	-8.47	-7.19	-22.08
	1	-36.24	-45.45	-45.59

Green = Best option

Depending on the value of the correlation coefficient, we make the following recommendations :

Correlation Coefficient (ρ)	Investment Recovered in	Recommendation
0	3.3 years	Pool Medium and Low Volume Products in the NDC and supply high volume products from the DCs.
0.5	7 years	
1	3 years	Very long payback period for the best option with NDC. Recommended to not open an NDC and continue current system.

Annexure A

Calculation of Annual Inventory & Distribution Cost of Current System

A.1 Calculating Annual Inventory Holding Cost:

The holding cost would be the overall cost of the following:

a) Cost of maintaining the safety stock levels inside the warehouse throughout the year
b) Cost of maintaining the cycle inventory, and
c) Holding cost incurred during all transits over a year

a) Safety Stock

Safety Stock level, $SS = \Phi^{-1}(CSL)*SQRT(T+L)*\sigma_{part}$

The total safety stock for each part is calculated in the following table:

	Region 1	Region 2	Region 3	Region 4	Region 5	Total Safety Stock
Part 1	38.07842896	35.3507478	28.69520578	18.98466086	24.4945768	**145.6036202**
Part 3	17.23894492	33.8232464	34.8597652	36.87824925	19.42108984	**142.2212956**
Part 7	10.80161738	7.74661449	13.03831593	20.51216231	21.71234202	**73.81105213**

Holding Cost per unit per day (h) = $ 0.15 (given)

Holding Cost for maintaining safety stock levels throughout the year = SS*365*h

Holding Cost Table for safety stock:

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1	$ 2,084.79	$ 1,935.45	$ 1,571.06	$ 1,039.41	$ 1,341.08
Part 3	$ 943.83	$ 1,851.82	$ 1,908.57	$ 2,019.08	$ 1,063.30
Part 7	$ 591.39	$ 424.13	$ 713.85	$ 1,123.04	$ 1,188.75

b) Cycle Inventory

Average Cycle time inventory, $Q_{avg} = Q_{part}/2 = (\mu_{part} *T)/2$

The total cycle time inventory for each part is calculated in the following table:

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1	106.44	67.83	52.98	35.43	10.08
Part 3	7.44	12.45	18.45	18.48	22.47
Part 7	1.44	2.19	2.4	5.82	7.62

Holding Cost for keeping cycle inventory = Average Cycle Inventory * h * 365

Cycle time inventory holding cost table:

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1	$ 5,827.59	$ 3,713.69	$ 2,900.66	$ 1,939.79	$ 551.88
Part 3	$ 407.34	$ 681.64	$ 1,010.14	$ 1,011.78	$ 1,230.23
Part 7	$ 78.84	$ 119.90	$ 131.40	$ 318.65	$ 417.20

c) In-Transit Inventory

Holding Cost of In-transit Inventory = μ_{part}*Transit Time*h*No. of Cycles per year

In-transit holding cost table:

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1	$ 7,770.12	$ 4,951.59	$ 3,867.54	$ 2,586.39	$ 735.84
Part 3	$ 543.12	$ 908.85	$ 1,346.85	$ 1,349.04	$ 1,640.31
Part 7	$ 105.12	$ 159.87	$ 175.20	$ 424.86	$ 556.26

Total holding Cost table =

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1	$ 15,682.50	$ 10,600.74	$ 8,339.26	$ 5,565.59	$ 2,628.80
Part 3	$ 1,894.29	$ 3,442.31	$ 4,265.56	$ 4,379.90	$ 3,933.85
Part 7	$ 775.35	$ 703.90	$ 1,020.45	$ 1,866.55	$ 2,162.21

A.2. Calculating Annual Transportation Cost:

Transportation Cost of a unit per day based on average daily demand = Demand per cycle*No. of cycles per year * Unit cost

Transportation cost table:

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1	$ 2,460.54	$ 1,568.00	$ 1,224.72	$ 819.02	$ 233.02
Part 3	$ 171.99	$ 287.80	$ 426.50	$ 427.20	$ 519.43
Part 7	$ 33.29	$ 50.63	$ 55.48	$ 134.54	$ 176.15

A.3. Total Cost

It is given that Of the 100 products that Alko sold, 10 were of type High (Part 1), 20 of type Medium (Part 3), and 70 of type Low (Part 7).

Total Cost per product type = (Holding cost + Transportation cost) *No. of items of the particular product type.

Total Annual Inventory and Distribution Costs for Current System with five DC's by part, region and total is as below :

	Region 1	Region 2	Region 3	Region 4	Region 5	Products with Similar Volume	Total Cost
Part 1	$ 18,143	$ 12,169	$ 9,564	$ 6,385	$ 2,862	10	$ 491,222
Part 3	$ 2,066	$ 3,730	$ 4,692	$ 4,807	$ 4,453	20	$ 394,977
Part 7	$ 809	$ 755	$ 1,076	$ 2,001	$ 2,338	70	$ 488,497
				Total Cost of Scenario 1			**$ 1,374,696**

Annexure B

Calculation of Annual Inventory & Distribution Cost of System with National Distribution Centre

B.1. Calculating Aggregate Demand

We show the calculations for Correlation Coefficient (ρ) = 0.5.

Calculations for ρ = 0, 1 are carried out similarly.

We first determine the covariances of demand distribution across regions for each part type.

Part 1	Region 1	Region 2	Region 3	Region 4	Region 5
Region 1		22.6152	18.3574	12.1452	15.6701
Region 2			17.0424	11.2752	14.5476
Region 3				9.1524	11.8087
Region 4					7.8126
Region 5					

Part 3	Region 1	Region 2	Region 3	Region 4	Region 5
Region 1		9.796	10.0962	10.6808	5.6248
Region 2			19.809	20.956	11.036
Region 3				21.5982	11.3742
Region 4					12.0328
Region 5					

Part 7	Region 1	Region 2	Region 3	Region 4	Region 5
Region 1		1.4058	2.3661	3.7224	3.9402
Region 2			1.6969	2.6696	2.8258
Region 3				4.4932	4.7561
Region 4					7.4824
Region 5					

Now, NDC Aggregate Demand = Sum of Expected Demand across regions

Standard Deviation of Aggregate Demand = $\sqrt{\sum\sigma^2 + 2\Sigma C_0 v_i}$

NDC Aggregate S.D.	S.D. of Aggregate Demand	NDC Aggregate Demand
Part 1	20.77263825	90.92
Part 3	20.3380653	26.43
Part 7	10.59924054	6.49

B.2 Calculating Annual Inventory Holding Cost:

The holding cost would be the overall cost of the following:

a) Cost of maintaining the safety stock levels inside the warehouse throughout the year
b) Cost of maintaining the cycle inventory, and
c) Holding cost incurred during all transits over a year

a) Safety Stock

To determine the safety stock,

Safety Stock level, $SS = \Phi^{-1}(CSL)*SQRT(T+L)*\sigma_{part}$

The total safety stock for each part is calculated in the following table:

	Total Safety Stock @NDC
Part 1	**113.3222679**
Part 3	**110.951515**
Part 7	**57.82269741**

b) Cycle Inventory

Average Cycle time inventory, $Q_{avg} = Q_{part}/2 = (\mu_{part} *T)/2$

The total cycle time inventory for each part is calculated in the following table:

	Average Cycle Inventory @NDC
Part 1	272.76
Part 3	79.29
Part 7	19.47

c) In-Transit Inventory

Holding Cost of In-transit Inventory = μ_{part}*Transit Time*h*No. of Cycles per year

Since the NDC is nearer to the factories, **we assume that actual transit time is 3 days.**

In-transit holding cost table:

	In-Transit Inventory Cost @NDC
Part 1	$ 14,933.61
Part 3	$ 4,341.13
Part 7	$ 1,065.98

d) **Total holding cost table (h * Inventory Held)**

	Region 5
Part 1	$ 36,071.61
Part 3	$ 14,756.85
Part 7	$ 5,297.76

B.3. Calculating Annual Transportation Cost:

Transportation Cost of a unit per day based on average daily demand = Demand per cycle*No. of cycles per year*Unit cost

Transportation cost table:

	Total Transportation Cost
Part 1	$ 9,623.88
Part 3	$ 2,797.62
Part 7	$ 686.97

B.4. Total Operating Cost

It is given that Of the 100 products that Alko sold, 10 were of type High (Part 1), 20 of type Medium (Part 3), and 70 of type Low (Part 7).

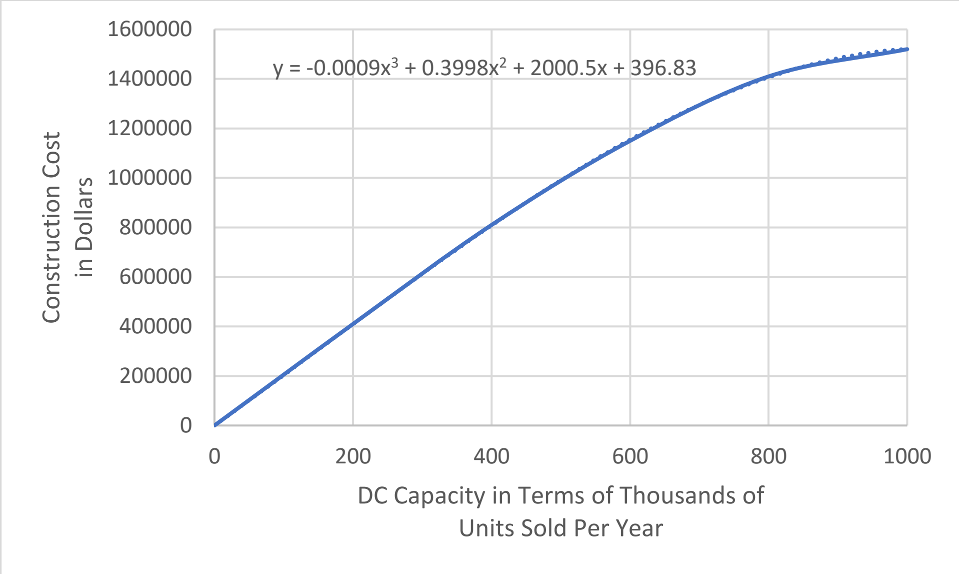
Total Cost per product type = (Holding cost + Transportation cost) *No. of items of the particular product type.

	Total Cost
Part 1	$ 456,954.96
Part 3	$ 351,089.32
Part 7	$ 418,930.69
Total	**$ 1,226,974.97**

Total Annual Operating Cost for system with NDC = **$ 1,226,974.97**

3.4 Cost of Construction of National Distribution Centre

We are given :



We fit a third degree polynomial to the data and obtain the equation as :

$$y = -0.0009x^3 + 0.3998x^2 + 2000.5x + 396.83$$

Since Construction Cost is a function of Annual Sales, we compute the total demand across all parts : (Daily Demand * 365 * No. of Products of this type)

Product Type	No, of Products of this Type	No. of Units Sold per Year
1	10	331858
3	20	192939
7	70	165819.5
		690,616.5

From this value of the total demand, we arrive at Construction Cost of NDC : **$ 1,276,208.91**

3.5 Cash Flow

We assume that the NDC Construction Amount is paid in three equal annual instalments with the first instalment in year 0.

We assume a lending rate of 12%.

Reduction in Annual Operational costs due to setting up NDC :

= Total Operating Cost of DC's – Total Operating Cost of NDC = **$ 147,720.64**

Year	Cash Flow
0	($531,348.28)
1	($531,348.28)
2	($531,348.28)
3	$250,000.00
NPV	($1,251,408.91)

Thus, No. of years required to start benefiting out of NDC investment :

= ($1,251,408.91)/ **$ 147,720.6**

= 8.5 years

Annexure C : Link to Excel Workbook

https://drive.google.com/open?id=1WVA-vd5WAq3WQMgBxbYnSpa11sjvFcdV