INTERNATIONAL UNIVERSITY OF HOCHIMINH CITY

SCHOOL OF INDUSTRIAL ENGINEERING AND MANAGEMENT

LOGISTICS ENGINEERING AND SUPPLY CHAIN DESIGN

ANALYZING AND ULTILIZING IN LOCATE DISTRIBUTION CENTER FOR INVENTORY MANAGEMENT OF ALKO INC

Advisor: Assoc.PhD. Nguyen Van Hop

Group 13:

No.	Student's name	Student's ID
1	Phạm Ngọc Huy	IELSIU19166
2	Trần Song Xuân Quỳnh	IELSIU20407
3	Nguyễn Hải Triều	IELSIU19293
4	Nguyễn Ngọc Trường	IELSIU19086

Ho Chi Minh, May 2023

TABLE OF CONTENTS

TABLES OF FIGURES

TABLES OF TABLES

1 Introduction

1.1 Problem statement

The margins had started to narrow as market competition grew, which led to a decline in the company's profitability. Gary Fisher was then engaged to reform and restructure the business, and he quickly realized that operating performance was the key. Gary established a task force to evaluate the organization's existing distribution system and make changes.

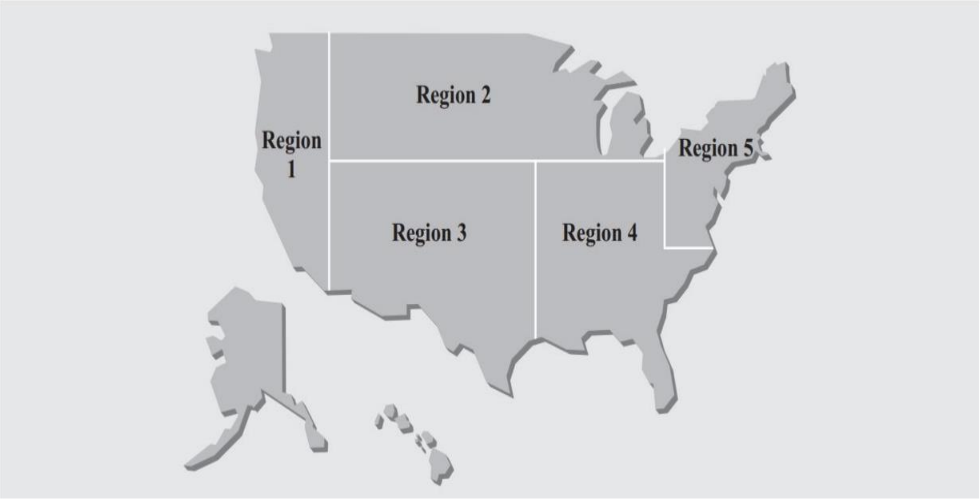

Figure 1: Sales Region for ALKO

1.1.1 Current Distribution System

Three Cleveland-area sites, where all of the production took place. The contiguous United States was split into five regions for sales purposes. In each of these areas, an ALKO-owned DC was in operation. Orders were shipped in TL quantities from the facilities to the DCs due to the typical huge order volumes. LTL shipments were made from the DC to the customer. Both transportation legs were handled by a third-party trucking business by ALKO. LTL shipping expenses from a DC to a customer averaged \$0.10 per unit in 2009, while TL costs from factories to DCs averaged \$0.09 per unit. Between the time a DC placed an order with a factory and the time the order was delivered from the plant, it took an average of five days.

The policy in 2009 was to stock each item in every DC. A thorough analysis of the product line revealed that, in terms of sales volume, there were three main groups of products. 10 of the 100 products ALKO sold fell into the High, 20 into the Medium, and 70 into the Low categories. The lead time for refilling was seven days. The DCs placed their orders using a periodic review policy with a ten-day ordering interval. Whether the unit was in transit or storage, the holding expense was \$0.2 per unit per day. To ensure a CSL of 95%, all DCs carried safety inventories.

1.1.2 Alternative Distribution Systems

The task force recommended ALKO shut down its five distribution centers and transfer all inventory to the NDC outside of Chicago. Yet, ALKO anticipated making $50,000 back for each warehouse it shuttered. 95% would continue to be the CSL for the NDC. The cost of inbound transportation from the facilities to the NDC would decrease to $0.05 per unit because Chicago is near to Cleveland. For orders coming from the Chicago NDC, the overall lead time for replenishment would still be five days. However, because of the longer average distance, the NDC would have to charge $0.24 more per unit for outbound transportation to customers.

1.1.3 Other possibilities

The task force considered include building a national distribution center while keeping the regional DCs open. In this case, some products would be stocked at the regional DCs, whereas others would be stocked at the NDC.

1.2 Objective

The "Managing Inventories at ALKO Inc." case study aims to explore the challenges associated with inventory management in a manufacturing company and develop strategies for optimizing inventory levels. The case study focuses on ALKO Inc., a company that produces a range of industrial chemicals, and the challenges it faces in managing its inventory levels efficiently. The case study requires analysis of the company's current inventory management practices, identifying areas for improvement, and developing a plan for optimizing inventory levels while minimizing costs and maintaining customer service levels.

1.3 Scope and Limitation

1.3.1 Scope

Limited to the solution and idea of centralization and decentralization in supply chain management, based on Chapter 12 of the book "Supply Chain Management: Strategy, Planning and Operation" by Sunil Chopra and Peter Meindl. The review covers the advantages and disadvantages of centralization and decentralization, as well as the potential benefits of a hybrid approach that combines elements of both approaches.

It should be noted that the choice between centralization and decentralization depends on various factors and can vary based on the specific needs and constraints of a company's supply chain. Additionally, while the literature suggests that a hybrid approach can offer benefits, the effectiveness of such an approach will depend on the specific implementation and management strategies used.

1.3.2 Limitation

This does not cover other potential solutions or ideas for inventory management in supply chain management beyond centralization and decentralization. There may be other viable solutions and ideas that are not included in this review.

1.4 Literature review

Chopra and Meindl (2016) also suggest that a hybrid approach that combines elements of both centralization and decentralization could be a viable solution in supply chain management. This approach can offer the benefits of both centralization and decentralization, while mitigating some of their drawbacks. For example, a company could centralize inventory for high-volume products that have consistent demand patterns and are less time-sensitive, while decentralizing inventory for low-volume products or products with high demand variability that require faster delivery times.

Other researchers have also explored the benefits and drawbacks of centralization and decentralization in supply chain management. For example, Lee et al. (2010) studied the impact of centralization and decentralization on inventory performance in a retail supply chain. They found that centralization can reduce inventory levels and improve inventory turnover, while decentralization can improve service levels and reduce stockouts.

Similarly, Wang et al. (2020) studied the impact of centralization and decentralization on supply chain risk management. They found that decentralization can reduce supply chain risks by diversifying the sources of supply and reducing the impact of disruptions at any one location.

In conclusion, centralization and decentralization are two contrasting approaches to inventory management in supply chain management. Each approach has its advantages and disadvantages, and the choice between centralization and decentralization depends on various factors such as transportation costs, lead times, order patterns, and product characteristics. A hybrid approach that combines elements of both centralization and decentralization could be a viable solution in supply chain management, offering the benefits of both approaches while mitigating some of their drawbacks.

2. Understand the case study and search for solution options.

2.1 Understand the case study

The case study of Managing Inventories at ALKO Inc focuses on a company that manufactures and distributes electronic components. ALKO Inc has a complex supply chain that involves multiple tiers of suppliers, a manufacturing plant, and distribution centers. The company is experiencing challenges with managing its inventory levels, which has resulted in stockouts, excess inventory, and increased costs.

2.2 Solution options

One potential solution for ALKO Inc to consider in managing its inventory is the centralization or decentralization of its distribution centers.

Centralization involves consolidating inventory in one or a few large distribution centers, while decentralization involves spreading inventory across multiple smaller distribution centers. The choice between centralization and decentralization will depend on various factors such as transportation costs, lead times, order patterns, and product characteristics.

Centralization:

Centralizing inventory in one or a few large distribution centers can offer several advantages. First, it can reduce transportation costs by consolidating shipments and using larger modes of transportation. Second, it can enable better inventory management by facilitating economies of scale and reducing excess inventory at individual locations. Finally, it can improve coordination and communication between the distribution centers, which can lead to better customer service and faster response times.

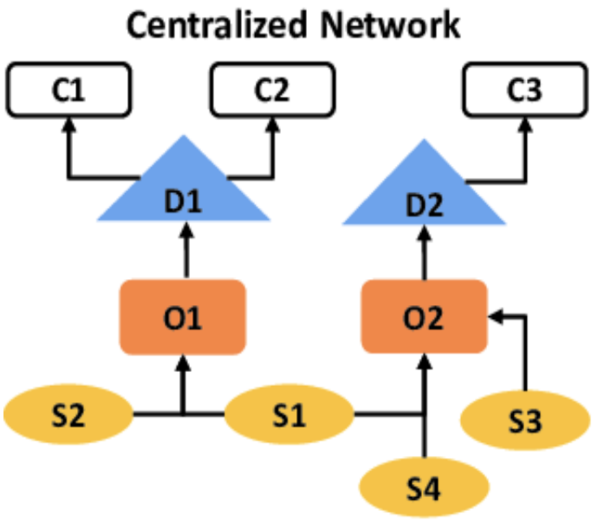

Figure 2: Illustrate for Centralization in Distribution Center Locating

Decentralization:

Decentralizing inventory across multiple smaller distribution centers can also offer advantages. First, it can reduce lead times and transportation costs by bringing inventory closer to customers. Second, it can improve customer service by providing faster delivery times and reducing stockouts. Finally, it can enable better risk management by distributing inventory across multiple locations, reducing the impact of disruptions at any one location.

Based on the specific circumstances of ALKO Inc., a hybrid approach may be the best option. By centralizing inventory management for high-demand products or those with long lead times, and decentralizing inventory management for low-demand products or those with short lead times, ALKO can achieve a balance between efficiency and flexibility, while ensuring optimal inventory levels and cost savings. This approach would require careful analysis of demand variability, lead times, and production capacity to ensure that inventory levels are managed effectively across the entire company.

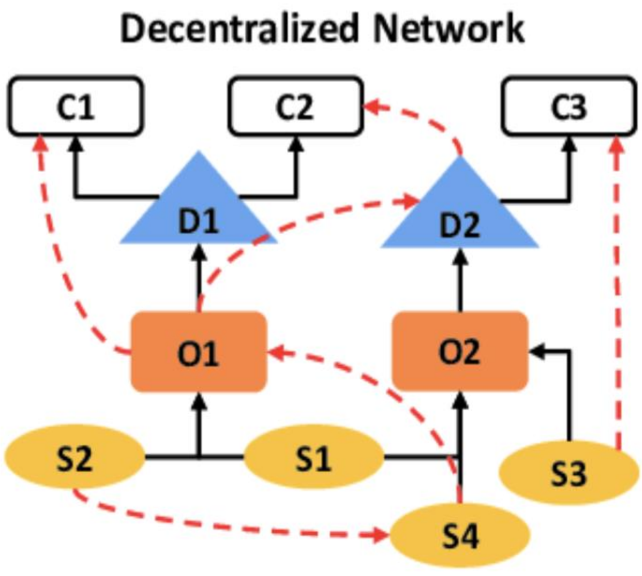

Figure 3:Illustrate for Decentralize in Distribution Center Locating

Hybrid approach centralization and decentralization:

A hybrid approach that combines elements of both centralization and decentralization could be a viable solution option for ALKO Inc. This approach can offer the benefits of both centralization and decentralization, while mitigating some of their drawbacks.

3. Analyze the advantage and disadvantages of the design options

In the case of ALKO company, the system should be designed in two forms, centralized and decentralized. Almost the whole condition of the matter is suitable to apply these two types of DC design in the company's case for efficient inventory management. Below is an analysis of the advantages and disadvantages of centralized and decentralized techniques.

Decentralized inventory management	Centralized inventory management	Hybrid approach
• Allows for greater flexibility in responding to local demand: Each location or department can manage its own inventory levels based on its specific needs and customer requirements. • Reduces the risk of stockouts: Decentralized inventory management ensures that each location maintains sufficient inventory levels to meet its own demand, reducing the risk of stockouts. • Encourages local ownership and accountability: By assigning inventory management responsibilities to individual locations or departments, employees	• Greater efficiency and cost savings: Consolidating inventory control into a single location or department can lead to greater efficiency, cost savings, and economies of scale. • Better coordination between departments: Centralized inventory management ensures better coordination between departments and a more cohesive inventory management strategy. • Provides a centralized view of inventory levels and demand: A centralized approach provides a more accurate view of inventory levels and demand across the entire company, enabling	• Improved customer service: By using a hybrid approach, ALKO Inc can offer faster delivery times and better customer service through the use of multiple locations. • Better inventory management: A hybrid approach can help the company achieve economies of scale for high-volume products while maintaining flexibility and responsiveness for low-volume products. • Reduced transportation costs: By centralizing inventory for high-volume products, ALKO Inc can achieve cost savings through the use of larger modes of

are more likely to take ownership of their inventory levels and be accountable for their performance.	better decision-making and optimization of inventory levels.	transportation and consolidated shipments. ● Reduced lead times: Decentralizing inventory for low-volume products can help reduce lead times and improve responsiveness to customer demand.

Table 1: The advantages of centralized and decentralized techniques

Decentralized inventory management	**Centralized inventory management**	**Hybrid approach**
● Can lead to inefficiencies and higher costs: Duplication of efforts and lack of coordination between departments can lead to inefficiencies, redundancies, and higher costs. ● May result in suboptimal inventory levels: Without a centralized view of inventory levels and demand, it can be difficult to optimize inventory levels across the entire company, resulting in	● Less responsive to local demand: A centralized approach may be less responsive to local demand and customer requirements, potentially leading to stockouts or excess inventory. ● Higher risk of stockouts if inventory levels are not managed effectively: A centralized approach requires effective management of inventory levels and demand to avoid stockouts or excess inventory.	● Increased inventory carrying costs: A hybrid approach can increase inventory carrying costs due to the need to maintain inventory in multiple locations. ● Complexity: Managing a hybrid distribution network can be more complex and require more resources than managing a centralized or decentralized network. ● Higher transportation costs: Decentralizing inventory can increase

suboptimal inventory levels and higher costs. ● May require additional training and resources: Decentralized inventory management requires each location or department to have the necessary training and resources to manage its own inventory levels effectively.	● May result in reduced employee ownership and accountability: Centralized inventory management may reduce employee ownership and accountability for inventory management, as individuals may feel less responsible for inventory levels.	transportation costs due to the need to transport inventory to multiple locations. ● Increased risk: A hybrid approach can increase the risk of stockouts and inventory imbalances if not managed properly.

Table 2: The disadvantages of centralized and decentralized techniques

4 Solving the case study by formulating and modeling

4.1 Formula work by individual

Decentralization Distribution Center for inventory management

Decentralization in distribution centers for inventory management involves delegating decision-making authority for inventory management to different levels or locations within the distribution network. This can offer benefits such as reduced transportation costs and improved customer service, but it can also increase complexity. To address this challenge, companies often use advanced inventory management software and systems to maintain visibility and control over inventory levels throughout the network.

- Demand during leadtime and time interval = (L+T)*Demand
- Standard deviation during leadtime and time interval = (L+T)*standard deviation
- Inventory cycle stock = Demand * Renew Interval /2
- Safety stock = NORMSINV(Customer service level)*standard deviation during leadtime and time interval
- Inventory cost per unit = ((Safety stock + Inventory cycle stock)/Mean Demand)*holding cost
- Transportation cost = cost shipping from factory to DC + cost shipping from DC to customer

- Annual Inventory cost and distribution cost = 365 * number of part * Mean Demand *(Inventory cost + Transportation cost)

Centralization Distribution Center for inventory management

A centralized distribution center is a facility where inventory is stored and managed for efficient distribution to various locations or customers. It allows companies to achieve economies of scale, reduce costs associated with transportation and storage, optimize inventory levels, and improve order fulfillment times. It can be a key component of a successful inventory management strategy.

- Mean Demand = Sum of demand per region
- Mean Demand during leadtime and time interval = (L+T)*Mean Demand
- Standard deviation = SQRT(sum((standard deviation per region)^2)
- Standard deviation during leadtime and time interval = (L+T)*standard deviation
- Inventory cycle stock = Mean demand * Renew Interval /2
- Safety stock = NORMSINV(Customer service level)*standard deviation during leadtime and time interval
- Inventory cost per unit = ((Safety stock + Inventory cycle stock)/Mean Demand)*holding cost
- Transportation cost = cost shipping from factory to DC + cost shipping from DC to customer
- Annual Inventory cost and distribution cost = 365 * number of part * Mean Demand *(Inventory cost + Transportation cost)

4.2 Data collection

The current distribution system at ALKO

- All production occurred at 3 facilities located in the Cleveland area.
- The plants scheduled production based on DC order.
- Orders were transported from plants to the DCs in TL quantities because order sizes tended to be large. In 2009, TL costs from the plants to DCs averaged $0.09 per unit.
- Customer placed orders with the DCs.
- Shipment from DC to customers were LTL. LTL shipping costs from DC to customer averaged $0.10 per unit.

- DC ordered using a periodic review policy with a reorder interval of 10 days.
- Lead time 7 days between the time a DC placed an order with a plant and the time the order was delivered from the plant.
- Holding cost $0.2 per unit per day.
- All DCs carried safety inventories to ensure a CSL of 95%.

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1 Mean	39.96	16.49	8.20	7.50	2.47
Part 1 SD	6.98	6.50	5.30	3.50	4.50
Part 3 Mean	0.32	2.14	4.16	5.16	8.13
Part 3 SD	3.20	6.20	6.40	6.80	3.55
Part 7 Mean	1.12	2.58	2.08	2.56	3.35
Part 7 SD	2.00	1.40	2.40	3.80	4.00

Table 3: Daily demand at ALKO

SALE: 100 PRODUCTS

- **Type High** = Part 1: 10 products
- **Type Medium** = Part 3: 20 products
- **Type Low** = Part 7: 70 products

Alternative Distribution System for ALKO

- ALKO expected to recover $50,000 for each warehouse that it closed.
- ALKO closed its current 5 DC.
- ALKO build a National Distribution Center (NDC) outside Chicago.
- Costs from Plant to NDC $0.05 per unit.

- Shipment cost from NDC to customer $ 0.24 per unit.
- Total replenishment for NDC still 5 days.
- The CSL out of NDC still continued 95%

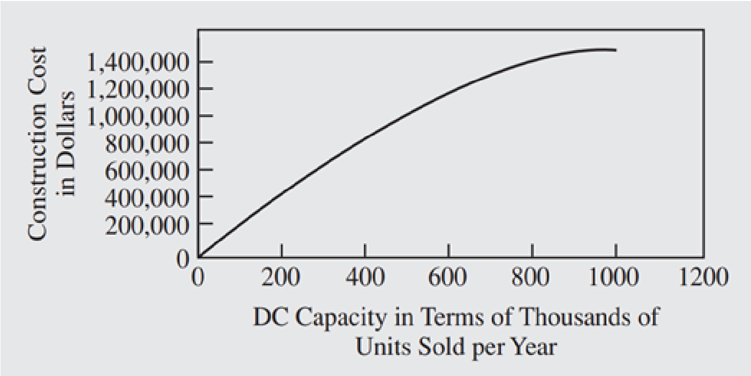

Table 4: Construction cost of NDC

x	y
200,000	400,000
400,000	800,000
500,000	1,000,000
600,000	1,100,000
800,000	1,400,000
1,000,000	1,500,000

Table 5: Corresponding values of x and y

$y = 2x$	$x \leq 500{,}000$
$y = 200{,}000 + 1.5x$	$500{,}000 < x \leq 800{,}000$
$y = 533{,}333.33333 + x$	$800{,}000 < x \leq 1{,}00{,}000$

Table 6: Piecewise - linear function (approximate)

4.3 Mathematical model

4.3.1 Decentralization mathematical model

Indices:

r = 5: regions

p = 3: parts to produce

Parameters:

Tj: transportation cost from factory to DC to customer per region j

ni: number of part i

h: holding cost per unit

dij: mean demand of part i per region j

sij: standard deviation of demand of part i per region j

l: leadtime to delivery to each region

IT: time interval on placed ordered

CSL: customer service level of the distribution center

Decistion variable:

stdij: standard deviation of demand of part i per region j during leadtime and time interval

daij: mean demand of part i per region j during leadtime and time interval

ICij: Inventory cycle of part i per region j

ssij: safety stock of part i per region j

Iij: Inventory cost of part i per region j

Objective function:

Minimize annual inventory cost per year:

$$\text{Minimize Z} = \sum_{i=1}^{p} \sum_{j=1}^{r} (365 * d_{ij}{}_{*n_i*(I_{ij}+T_j)})$$

Constraints:

Constraint 1: Calculate demand during leadtime and time interval

$$da_{ij} = (l + IT) * d_{ij} \qquad \forall i \in p, \forall j \in r (1)$$

Constraint 2: Calculate standard deviation during leadtime and time interval

$$std_{ij} = \sqrt{(l + IT) * (s_{ij}{}^2)} \qquad \forall i \in p, \forall j \in r \ (2)$$

Constraint 3: Calculate Inventory Cycle of part per region

$$IC_{ij} = \frac{d_{ij} * IT}{2} \qquad \forall i \in p, \forall j \in r \ (3)$$

Constraint 4: Calculate safety stock of part per region

$$ss_{ij} = F_s^{-1}(CSL) * std_{ij} \qquad \forall i \in p, \forall j \in r \ (4)$$

Constraint 5: Calculate Inventory cost per unit per region

$$I_{ij} = \left(\frac{ss_{ij} + IC_{ij}}{d_{ij}}\right) * h \qquad \forall i \in p, \forall j \in r \ (5)$$

4.3.2 Centralization mathematical model

Indices:

r = 5: regions

p = 3: parts to produce

Parameters:

Ti: transportation cost from factory to NDC to customer

ni: number of part i

h: holding cost per unit

dij: mean demand of part i per region j

sij: standard deviation of demand of part i per region j l: leadtime to delivery to each region

IT: time interval on placed ordered

CSL: customer service level of the distribution center

Decistion variable:

stdi: Central standard deviation of demand of part i per region j during leadtime and time interval

dai: Central mean demand of part i per region j during leadtime and time interval

ICi: Central inventory cycle of part i per region j

ssi: Central safety stock of part i per region j

Ii: Central inventory cost of part i per region j

Objective function:

Minimize annual inventory cost per year:

$$\text{Minimize Z} = \sum_{i=1}^{p} \sum_{j=1}^{r} (365 * d_{ij_{*n_i*(I_i+T_i)}})$$

Constraints:

Constraint 1: Calculate standard deviation during leadtime and time interval

$$std_i = \sqrt{\sum_{j=1}^{r} ((l + IT) * (s_{ij}{}^2))} \qquad \forall i \epsilon p \ (1)$$

Constraint 2: Calculate Inventory Cycle of part per region

$$IC_i = \frac{\sum_{j=1}^{r} (d_{ij} * IT)}{2} \qquad \forall i \epsilon p \ (2)$$

Constraint 3: Calculate safety stock of part per region

$$ss_i = F_s^{-1}(CSL) * std_i \qquad \forall i \epsilon p \ (3)$$

Constraint 4: Calculate Inventory cost per unit per region

$$I_i = \left(\frac{ss_i + IC_i}{\sum_{j=1}^{r} d_{ij}}\right) * h \qquad \forall i \epsilon p \ (4)$$

4.3.3 Hybrid mathematical model

Indices:

r = 5: number of regions

p = 3: number of parts

Parameters:

Ti: transportation cost per part i from DCs to customers

Tj: transportation cost per part i from NDC to customers

ni: number of part i sale during 100 parts

dij: demand per part i per region j

h: holding cost per unit

sij: standard deviation of demand per part i per region j

numdc: number of distribution center that at least to have in hybrid model

ld: leadtime of DCs

lc: leadtime of NDC

IT: time interval of inventory

CSL: customer service level, which are turning to z-score

Decision variable:

- **For Centralization**

x1i: number of part i will be delivered from NDC

y1i: if y1i = 0 - part i will not use NDC, if y1i = 1 - part i will use NDC

std1i: standard deviation of demand in NDC per part i

IC1i: Inventory cycle in NDC per part i

I1i: Inventory cost in NDC per part i

ss1i: safety stock in NDC per part i

- **For decentralization**

x2ij: number of part i will be delivered to per region j.

y2ij: if y2ij = 0 - part i will not use DCs, if y2ij = 1 - part i will use DCs.

std2ij: standard deviation of demand in DCs per part i per region j.

IC2ij: Inventory cycle in DCs per part i per region j.

I2ij: Inventory cost in DCs per part i per region j.

ss2ij: safety stock in DCs per part i per region j.

- **Define binary in centralization or decentralization or not**

$centralized_i$: if = 1 - part i will be centralized, = 0 - part i will be decentralized

$decentralized_i$: if = 1 - part i will be decentralized, = 0 part i will be centralized

Objective function:

$$\sum_{i=1}^{p}\sum_{j=1}^{r}(decentralized_i * d_{ij} * n_i * 365 * (I2_{ij} + T2_j) + (centralized_i * d_{ij} * n_i * 365 * (I1_i + T1_i)))$$

Constraints:

Constraint 1: At least one part must be centralized

$$\sum_{i=1}^{p} centralized_i >= 1 \qquad (1)$$

Constraint 2: A part can either be centralized or decentralized, but not both

$$centralized_i + decentralized_i = 1 \qquad ,\forall i \epsilon p (2)$$

Constraint 3: At least one part must be decentralized

$$\sum_{i=1}^{p} y2_{ij} \geq 1 \qquad ,\forall j \epsilon r (3)$$

Constraint 4: If part i is centralized, set decentralization variables to 0

$$decentralized_i \leq 1 - centralized_i \qquad ,\forall i \epsilon p (4)$$

$$y2_{ij} \leq 1 - centralized_i \qquad ,\forall i \epsilon p, \forall j \epsilon r (5)$$

Constraint 5: If part i is decentralized, set centralization variables to 0

$$centralized_i \leq 1 - decentralized_i \qquad ,\forall i \epsilon p (6)$$

$$y1_i \leq 1 - decentralized_i \qquad ,\forall i \epsilon p (7)$$

Constraint 6: The total number of data centers must be at least numdc

$$\sum_{i=1}^{p} y1_i + \sum_{i=1}^{p}\sum_{j=1}^{r} y2_{ij} \geq numdc$$

Constraint 7: Compute the centralized demand for each part

$$x2_{ij} = (1 - centralized_i) * d_{ij} \quad , \quad \forall i \in p, \forall j \in r \quad (8)$$

Constraint 8: Compute the decentralized demand for each part and region

$$x1_i = (1 - decentralized_i) * \sum_{j=1}^{r} d_{ij} \quad , \quad \forall i \in p \ (9)$$

Constraint 9: Calculate standard deviation during lead time of decentralized

$$std2_{ij} = \sqrt{(ld + IT) * (s_{ij}{}^2)} \quad \forall i \in p, \forall j \in r \quad (10)$$

Constraint 10: Calculate inventory cycle of decentralized

$$IC2_{ij} = \frac{d_{ij} * IT}{2} \quad \forall i \in p, \forall j \in r \quad (11)$$

Constraint 11: Calculate safety stock of decentralized

$$ss2_{ij} = F_S^{-1}(CSL) * std2_{ij} \quad \forall i \in p, \forall j \in r \quad (12)$$

Constraint 12: Calculate inventory cost per unit of decentralized

$$I2_{ij} = (\frac{ss2_{ij} + IC2_{ij}}{d_{ij}}) * h \quad \forall i \in p, \forall j \in r \quad (13)$$

Constraint 13: Calculate standard deviation during lead time of centralized

$$std1_i = \sqrt{\sum_{j=1}^{r}((lc + IT) * (s_{ij}{}^2))} \quad \forall i \in p \ (14)$$

Constraint 14: Calculate inventory cycle of centralized

$$IC1_i = \frac{\sum_{j=1}^{r}(d_{ij} * IT)}{2} \quad \forall i \in p \ (15)$$

Constraint 15: Calculate safety stock of centralized

$$ss1_i = F_S^{-1}(CSL) * std1_i \quad \forall i \in p \ (16)$$

Constraint 16: Calculate inventory cost per unit of centralized

$$I1_i = \left(\frac{ss1_i + IC1_i}{\sum_{j=1}^{r} d_{ij}}\right) * h \qquad \forall i \in p \; (17)$$

5. Conduct result analysis and sensitivity analysis.

5.1 Result Analysis

5.1.1 Formula work by individual

a. Decentralization in the distribution center for inventory management

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1 Mean	39.96	16.49	8.2	7.5	2.47
Part 1 SD	6.98	6.5	5.3	3.5	4.5
Part 3 Mean	0.32	2.14	4.16	5.16	8.13
Part 3 SD	3.2	6.2	6.4	6.8	3.55
Part 7 Mean	1.12	2.58	2.08	2.56	3.35
Part 7 SD	2	1.4	2.4	3.8	4

Table 7: Demand (a)

	Region 1	Region 2	Region 3	Region 4	Region 5
Part 1 Mean	679.32	280.33	139.4	127.5	41.99
Part 1 SD	28.77927727	26.80018657	21.85245982	14.43086969	18.55397532
Part 3 Mean	5.44	36.38	70.72	87.72	138.21
Part 3 SD	13.193938	25.56325488	26,387876	28,03711825	14,63702497
Part 7 Mean	19.04	43.86	35.36	43.52	56.95
Part 7 SD	8.246211251	5.772347876	9.895453501	15.66780138	16.4924225

Table 8: Demand during lead time and time interval (a)

	Region 1	Region 2	Region 3	Region 4	Region 5
P1 Cycle inventory	199,8	82,45	41	37,5	12,35
P3 Cycle inventory	1,6	10,7	20,8	25,8	40,65
P7 Cycle inventory	5,6	12,9	10,4	12,8	16,75

Table 9: Cycle Inventory (a)

	Region 1	Region 2	Region 3	Region 4	Region 5
P1 SS	47,33769854	44,08238403	35,94409775	23,73666832	30,51857356
P3 SS	21,70209675	42,04781246	43,4041935	46,1169556	24,07576358
P7 SS	13,56381047	9,494667329	16,27657256	25,77123989	27,12762094

Table 10: Safety stock (a)

Cost per unit	Region 1	Region 2	Region 3	Region 4	Region 5
Inventory cost	1,236925418	1,534655962	1,876685311	1,632977822	3,471139559
Transportation cost	0,19	0,19	0,19	0,19	0,19
Total cost part 1	1,426925418	1,724655962	2,066685311	1,822977822	3,661139559
Inventory cost	14,56381047	4,929702099	3,086740072	2,787478899	1,592269707
Transportation cost	0,19	0,19	0,19	0,19	0,19
Total cost part 2	14,75381047	5,119702099	3,276740072	2,977478899	1,782269707
Inventory cost	3,422109013	1,736020723	2,565055054	3,013378117	2,619559459
Transportation cost	0,19	0,19	0,19	0,19	0,19

Total cost part 3	3,612109013	1,926020723	2,755055054	3,203378117	2,809559459

Table 11: Cost per unit (a)

	# of parts	Region 1	Region 2	Region 3	Region 4	Region 5	All Region
Part 1	10	208122,7799	103804,4553	61855,89135	49904,01788	33007,0037	456694,1482
Part 3	20	34464,90126	79979,98619	99508,04252	112155,6752	105775,9248	431884,53
Part 7	70	103364,1115	126961,3601	146414,6458	209526,5559	240477,218	826743,8912
All parts		345951,7927	310745,8016	307778,5797	371586,2489	379260,1465	1715322,569

Table 12: Annual inventory cost and distribution cost (a)

b. Centralization in the distribution center for inventory management

	Region 1	Region 2	Region 3	Region 4	Region 5	Central
Part 1 Mean	39.96	16.49	8.2	7.5	2.47	74.62
Part 1 SD	6.98	6.5	5.3	3.5	4.5	12.31099
Part 3 Mean	0.32	2.14	4.16	5.16	8.13	19.91
Part 3 SD	3.2	6.2	6.4	6.8	3.55	12.18534
Part 7 Mean	1.12	2.58	2.08	2.56	3.35	11.69
Part 7 SD	2	1.4	2.4	3.8	4	6.493073

Table 13: Demand (b)

	Central
Part 1 Mean	1119.3
Part 1 SD	47.68025
Part 3 Mean	298.65
Part 3 SD	47.19362
Part 7 Mean	175.35
Part 7 SD	25.14756

Table 14: Demand during lead time and time interval (b)

	Central
P1 Cycle inventory	373.1
P3 Cycle inventory	99.55
P7 Cycle inventory	58.45

Table 15: Cycle inventory (b)

	Central
P1	78.42703
P3	77.62659
P7	41.36406

Table 16: Safety stock (b)

Cost per unit	Central
Inventory cost	1.210204
Transportation cost	0.29
Total cost part 1	1.500204
Inventory cost	1.779775
Transportation cost	0.29
Total cost part 2	2.069775
Inventory cost	1.707683
Transportation cost	0.29
Total cost part 3	1.997683

Table 17: Cost per unit (b)

	# of parts	Central
Part 1	10	408600.0004
Part 3	20	300827.2948
Part 7	70	596666.9152
All parts	100	1306094.21

Table 18: Annual inventory and distribution cost (b)

c. Hybrid - Part 1 Decentralization/Other part centralization

	Region 1	Region 2	Region 3	Region 4	Region 5	Central
Part 1 Mean	39,96	16,49	8,2	7,5	2,47	
Part 1 SD	6,98	6,5	5,3	3,5	4,5	
Part 3 Mean						19,91
Part 3 SD						12,18533955
Part 7 Mean						11,69
Part 7 SD						6,493073232

Table 19: Demand (c)

	Region 1	Region 2	Region 3	Region 4	Region 5	Central
Part 1 Mean	679,32	280,33	139,4	127,5	41,99	
Part 1 SD	28,77927727	26,80018657	21,85245982	14,43086969	18,55397532	50,7594996
Part 3 Mean						298,65
Part 3 SD						47,19361715
Part 7 Mean						175,35
Part 7 SD						25,14756449

Table 20: Demand during leadtime and time interval (c)

	Region 1	Region 2	Region 3	Region 4	Region 5	Central
P1 Cycle inventory	199,8	82,45	41	37,5	12,35	
P3 Cycle inventory						99,55
P7 Cycle inventory						58,45

Table 21: Inventory cycle (c)

	Region1	Region 2	Region 3	Region 4	Region 5	Central
Part 1	47,33769854	44,08238403	35,94409775	23,73666832	30,51857356	
Part 3						77,62659226
Part 7						41,36406262

Table 22: Safety stock (c)

Cost per unit	Region 1	Region 2	Region 3	Region 4	Region 5	Central
Inventory cost	1,236925418	1,534655962	1,876685311	1,632977822	3,471139559	
Transportation cost	0,19	0,19	0,19	0,19	0,19	
Total cost part 1	1,426925418	1,724655962	2,066685311	1,822977822	3,661139559	
Inventory cost						1,77977491
Transportation cost						0,29
Total cost part 2						2,06977491
Inventory cost						1,707682851
Transportation cost						0,29

Total cost part 3						1,997682851

Table 23: Cost per unit (c)

	# of parts	Region 1	Region 2	Region 3	Region 4	Region 5	Total/ Central
Part 1	10	208122,7799	103804,4553	61855,89135	49904,01788	33007,0037	456694,1482
Part 3	20						300827,2947
Part 7	70						596666,915
All parts							1354188,358

Table 24: Annual inventory cost and distribution cost (c)

d. Part 1 is decentralization, Part 1 region 3 served by region 2, Part 1 region 5 served by region 4, and other parts are centralization

	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Central**
Part 1 Mean	39,96	16,49	8,2	7,5	2,47	74,62
Part 1 SD	6,98	6,5	5,3	3,5	4,5	12,31098696
Part 3 Mean	0,32	2,14	4,16	5,16	8,13	19,91
Part 3 SD	3,2	6,2	6,4	6,8	3,55	12,18533955
Part 7 Mean	1,12	2,58	2,08	2,56	3,35	11,69
Part 7 SD	2	1,4	2,4	3,8	4	6,493073232

Table 25: Demand (d)

	Region 1	Region 2	Region 3	Region 4	Region 5	Central
Part 1 Mean	679,32	419,73		169,49		
Part 1 SD	28,77927727	34,58005205		23,50531855		
Part 3 Mean						298,65
Part 3 SD						47,19361715
Part 7 Mean						175,35
Part 7 SD						25,14756449

Table 26: Demand, standard deviation during leadtime and interval time (d)

	Region 1	Region 2	Region 3	Region 4	Region 5	Central
Part 1 Batch Stock	199,8	82,45		37,5		
P3 Cycle inventory						99,55
P7 Cycle inventory						58,45

Table 27: Cycle Inventory (d)

	Region1	Region 2	Region 3	Region 4	Region 5	Central
Part 1	47,33769854	56,87912398		38,66280842		
Part 3						77,62659226
Part 7						41,36406262

Table 28: Safety stock (d)

Transportation for batch stock = transportation cost from fac to DC + transportation cost from DC to region 1 + transportation cost from DC to region 2

Cost per unit	Region 1	Region 2	Region 3	Region 4	Region 5	Central
Inventory cost	1,236925418	1,128627979		1,527839688		
Transportation cost	0,19	0,29		0,29		
Total cost part1	1,426925418	1,418627979		1,817839688		
Inventory cost						1,77977491
Transportation cost						0,29
Total cost part2						2,06977491
Inventory cost						1,707682851
Transportation cost						0,29
Total cost part3						1,997682851

Table 29: Cost per unit (d)

	# of parts	Region 1	Region 2	Region 3	Region 4	Region 5	Central
Part 1	10	208122,7799	127844,6255	0	66152,09515	0	402119,5006
Part 3	20						300827,2947
Part 7	70						596666,915
All parts							1299613,71

Table 30: Annual Inventory and Distribution cost (d)

5.2 Summary cost saving and best solution

Option	Inventory and distribution cost	Construction Decentralize	Construction Centralize	Total Cost
Decentralization (Current distribution)	$ 1,715,322.569	$ 250,000	$0	$ 1,965,322.569
Centralization (NDC solution)	$ 1,306,094.21	- $ 250,000	$77,540.6	$ 1,133,634.82
Hybrid - Part 1 Decentralization - Other part centralization	$ 1,354,188.358	$ 250,000	$23,068	$ 1,627,256.358
Hybrid - Part 1 is decentralization, Part 1 region 3 served by region 2, Part 1 region 5 served by region 4, and other parts are centralization	$ 1,299,613.71	$ 150,000	$23,068	$ 1,472,681.71

Table 31: Summary cost saving

6. Conclustion

Based on the analysis that was conducted, it has been determined that the optimal solution for the distribution center problem is to implement a centralized approach by building a National Distribution Center (NDC), with a total cost of $1,133,634.82. This solution was selected after a rigorous evaluation of various factors, such as the size of the distribution center, the nature of the products being distributed, the geographical locations of the regions, and the supply chain strategy of the organization.

Centralization has been recognized as an effective approach for improving supply chain efficiency in certain circumstances. By consolidating inventory into a single location, a centralized distribution center can reduce transportation costs, improve inventory accuracy, and increase responsiveness to changes in demand. In addition, a centralized approach can provide greater control over inventory management, reducing the likelihood of stockouts or excess inventory.

It is important to note, however, that the decision to implement a centralized approach should be made based on a comprehensive analysis of the specific supply chain context. Factors such as lead times, transportation costs, and inventory carrying costs must be carefully evaluated to determine the potential benefits of a centralized distribution center. It is also important to consider the potential trade-offs and risks associated with a centralized approach, such as increased vulnerability to disruptions or longer lead times for customers located far from the NDC. By carefully weighing these factors, organizations can make informed decisions about the most appropriate supply chain strategy for their specific needs.

APPENDIX

1. Decentralize

```
/*********************************************
 * OPL 12.8.0.0 Model
 * Author: admin
 * Creation Date: May 1, 2023 at 7:15:44 PM
 *********************************************/
int r = 5;
int p = 3;
range region = 1..r;
range part = 1..p;
float T[region] = [0.19, 0.19, 0.19, 0.19, 0.19];
int n[part] = [10,20,70];
float d[part][region] = [[39.96, 16.49, 8.20, 7.50, 2.47],
                         [0.32, 2.14, 4.16, 5.16, 8.13],
                          [1.12, 2.58, 2.08, 2.56, 3.35]];
float h = 0.2;
float s[part][region] = [[6.98, 6.50, 5.30, 3.50, 4.50],
                         [3.20, 6.20, 6.40, 6.80, 3.55],
                         [2.00, 1.40, 2.40, 3.80, 4.00]];
int l = 7;
int IT = 10;
float CSL = 1.64485362695147;
dvar float+ std[part][region];
dvar float+ IC[part][region];
dvar float+ I[part][region];
dvar float+ ss[part][region];
dvar float+ da[part][region];
```

```
minimize sum(j in region, i in part)(365*d[i][j]*n[i]*(I[i][j]+ T[j]));

subject to{
//constraint 1: calculate demand during leadtime
forall(i in part,j in region){
da[i][j] == (l + IT)*d[i][j];
//constraint 2: calculate standard during leadtime
std[i][j] == sqrt((l + IT)*(s[i][j])^2);
}
//constraint 3: calculate inventory cycle
forall( j in region, i in part){
IC[i][j] == (d[i][j]*IT)/2;
//constraint 4: calculate safety stock
ss[i][j] == CSL*std[i][j];
//constraint 5: calculate inventory cost per unit
I[i][j] == ((ss[i][j] + IC[i][j])/d[i][j])*h;
}
}
```

2. Centralization

```
/*********************************************
 * OPL 12.8.0.0 Model
 * Author: admin
 * Creation Date: May 1, 2023 at 7:15:44 PM
 *********************************************/
int r = 5;
int p = 3;
range region = 1..r;
```

```
range part = 1..p;
float T[part] = [0.29, 0.29, 0.29];
int n[part] = [10,20,70];
float d[part][region] = [[39.96, 16.49, 8.20, 7.50, 2.47],
                         [0.32, 2.14, 4.16, 5.16, 8.13],
                         [1.12, 2.58, 2.08, 2.56, 3.35]];
float h = 0.2;
float s[part][region] = [[6.98, 6.50, 5.30, 3.50, 4.50],
                         [3.20, 6.20, 6.40, 6.80, 3.55],
                         [2.00, 1.40, 2.40, 3.80, 4.00]];
int l = 5;
int IT = 10;
float CSL = 1.64485362695147;
dvar float+ std[part];
dvar float+ IC[part];
dvar float+ I[part];
dvar float+ ss[part];

minimize sum(i in part, j in region)(365*d[i][j]*n[i]*(I[i]+ T[i]));

subject to{
forall(i in part){
//constraint 1: calculate standard during leadtime
std[i] == sqrt(sum(j in region)((l + IT)*(s[i][j])^2));
}
//constraint 2: calculate inventory cycle
forall(i in part){
IC[i] == sum(j in region)((d[i][j]*IT)/2);
```

```
//constraint 3: calculate safety stock
ss[i] == CSL*std[i];
//constraint 4: calculate inventory cost per unit
I[i] == ((ss[i] + IC[i])/sum(j in region)d[i][j])*h;
}
}
```

3. Hybrid of Centralization and Decentralization

```
/*********************    ***********************
* OPL 12.8.0.0 Model
* Author: admin
* Creation Date: May 11, 2023 at 12:39:14 AM
*********************************************/
int r = 5;
int p = 3;
range region = 1..r;
range part = 1..p;
float T1[part] = [0.29, 0.29, 0.29];
float T2[region] = [0.19, 0.19, 0.19, 0.19, 0.19];
int n[part] = [10, 20, 70];
float d[part][region] = [
   [39.96, 16.49, 8.20, 7.50, 2.47],
   [0.32, 2.14, 4.16, 5.16, 8.13],
   [1.12, 2.58, 2.08, 2.56, 3.35]
];
float h = 0.2;
float s[part][region] = [
   [6.98, 6.50, 5.30, 3.50, 4.50],
   [3.20, 6.20, 6.40, 6.80, 3.55],
```

```
  [2.00, 1.40, 2.40, 3.80, 4.00]
];
int numdc = 5;
int lc = 5;
int ld = 7;
int IT = 10;
float CSL = 1.64485362695147;
// Centralization
dvar float+ x1[part];
dvar boolean y1[part];
dvar float+ std1[part];
dvar float+ IC1[part];
dvar float+ I1[part];
dvar float+ ss1[part];

// Decentralization
dvar boolean y2[part][region];
dvar float+ x2[part][region];
dvar float+ std2[part][region];
dvar float+ IC2[part][region];
dvar float+ I2[part][region];
dvar float+ ss2[part][region];

//decide to centralization or decentralization
dvar boolean centralized[part];
dvar boolean decentralized[part];

// Expressions for inventory management
```

```
	dexpr float cd = sum(i in part, j in region)(decentralized[i]*d[i][j]*n[i]*365*(I2[i][j]+T2[j]));
	dexpr float cc = sum(i in part, j in region)(centralized[i]*d[i][j]*n[i]*365*(I1[i]+T1[i]));


	// Objective function
	minimize cc + cd;


	subject to {
	  // Constraint 1: At least one part must be centralized
	  sum(i in part) centralized[i] >= 1;
	  // Constraint 2: A part can either be centralized or decentralized, but not both
	  forall(i in part) {
		centralized[i] + decentralized[i] == 1;
		}
		forall(j in region){
		  sum(i in part) y2[i][j] >= 1;
		}
		//forall(i in part){
		//	sum(j in region) y2[i][j] == 5;
		//}
	  // Constraint 3: If part i is centralized, set decentralization variables to 0
		forall(i in part) {
		decentralized[i] <= 1 - centralized[i];
	}
	forall(i in part,j in region) {
	y2[i][j] <= 1 - centralized[i];
	}
```

```
        // Constraint 4: If part i is decentralized, set centralization variables to 0
        forall(i in part) {
        centralized[i] <= 1 - decentralized[i];
        y1[i] <= 1 - decentralized[i];
        }
    // Constraint 5: The total number of data centers must be at least numdc
   sum(i in part) y1[i] + sum(i in part, j in region) y2[i][j] >= numdc;

    // Constraint 6: Compute the centralized demand for each part
    forall(i in part, j in region) {
  x2[i][j] == (1 - centralized[i]) * d[i][j];
    }

    // Constraint 7: Compute the decentralized demand for each part and region
    forall(i in part, j in region) {
  x1[i] == (1 - decentralized[i]) * sum(j in region) d[i][j];
    }
    // DECENTRALIZATION
    // Constraint 8: Calculate standard deviation during lead time
    forall(i in part, j in region) {
      std2[i][j] == sqrt((ld + IT) * (s[i][j]) ^ 2);
    }

    // Constraint 9: Calculate inventory cycle
    forall(i in part, j in region) {
      IC2[i][j] == (x2[i][j] * IT) / 2;

      // Constraint 9: Calculate safety stock
```

```
        ss2[i][j] == CSL * std2[i][j];

        // Constraint 10: Calculate inventory cost per unit
        I2[i][j] == ((ss2[i][j] + IC2[i][j]) / d[i][j]) * h;
    }

    // CENTRALIZATION
    // Constraint 11: Calculate standard deviation during lead time
    forall(i in part) {
        std1[i] == sqrt(sum(j in region) ((lc + IT) * (s[i][j]) ^ 2));
    }

    // Constraint 12: Calculate inventory cycle
    forall(i in part) {
        IC1[i] == (x1[i] * IT) / 2;

        // Constraint 13: Calculate safety stock
        ss1[i] == CSL * std1[i];

        // Constraint 14: Calculate inventory cost per unit
        I1[i] == ((ss1[i] + IC1[i]) / sum(j in region) d[i][j]) * h;
    }
}
```

REFERENCES

1. Chopra, S., & Meindl, P. (2018). *Supply Chain Management STRATEGY, PLANNING, AND OPERATION*. https://base-logistique-services.com/storage/app/media/Chopra_Meindl_SCM.pdf

2. Helmrich, Alysha, et al. "Centralization and Decentralization for Resilient Infrastructure and Complexity." *Environmental Research: Infrastructure and Sustainability*, vol. 1, no. 2, 16 July 2021, p. 021001, https://doi.org/10.1088/2634-4505/ac0a4f.

3. Wang, Feng, et al. "The Laboratory Tests and Host Immunity of COVID-19 Patients with Different Severity of Illness." *JCI Insight*, vol. 5, no. 10, 21 May 2020, https://doi.org/10.1172/jci.insight.137799. Accessed 1 Dec. 2020.

4. Watson, Michael, et al. *Supply Chain Network Design: Applying Optimization and Analytics to the Global Supply Chain*. *Google Books*, FT Press, 20 Aug. 2012, books.google.com.pe/books?id=u_li_M7-jeQC&printsec=copyright#v=onepage&q&f=false. Accessed 6 May 2023.

5. Minis, Loannis, et al. *Supply Chain Optimization, Design, and Management: Advances and Intelligent Methods*.

6. Kohn, Christofer. *Dissertations from the International Centralisation of Distribution Systems and Its Environmental Effects*.

CONTRIBUTION TABLE

No.	Student's name	Student's ID	Contribution
1	Phạm Ngọc Huy	IELSIU19166	
2	Nguyễn Hải Triều	IELSIU19293	
3	Trần Song Xuân Quỳnh	IELSIU20407	
4	Nguyễn Ngọc Trường	IELSIU19086	