SUPPLY CHAIN DESIGN FOR ABALONE FARMING IN THAILAND

by

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A Research Paper

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Abstract

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Problem statement: Design Supply Chain System for abalone to turn abalone farming research into a successful commercial industry. Significance of my proposed research is to design a model that involves many parties, such as researchers, farmers who received the technological transfer from the researchers, intermediates, and customers. Decision theory is the technique used to develop this supply chain model. The model decides the locations e.g. warehouses and distribution centers, which is an important role in planning process. The data required are farm locations, fixed cost and variable cost of each location, demands, and transportation costs. The software to be used is Microsoft Excel. This simulation model will help the planner to plan the supply chain system.

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TABLE OF CONTENTS

LIST OF FIGURES

Figures

LIST OF TABLES

Tables

Chapter 1

Supply Chain Design for Abalone Farming in Thailand

1.1 Rationale

The requirements of Research and Development (R&D) projects for rural development are necessary so that the old processes are changed to the newly developed processes to improve the quality and efficiency of the products and services. The Office of Technology Promotion and Transfer, OTPT, receives a budget from the government every year to support R&D projects as shown in Figure 1.1. Like many other organizations in Thailand that support R&D projects, OTPT found that most R&D projects do not reach business units and that the budget is declining every year. For example, OTPT received a maximum budget in 1993 which was more than 16 million baht and this amount of money could create 24 R& D projects, but, in 2003, it was decreased to 2.9 million baht so only 9 projects were created, (OTPT 2003).

Invention Project for Rural Development			
Year-BE	Year	No. of Project	Budget(Baht)
2535	1992	11	7,638,800
2536	1993	24	16,001,744
2537	1994	11	4,745,500
2538	1995	11	5,971,950
2539	1996	14	7,679,760
2540	1997	19	8,963,962
2541	1998	12	6,359,500
2542	1999	13	6,400,710
2543	2000	12	4,441,415
2544	2001	13	4,898,120
2545	2002	8	2,613,796
2546	2003	9	2,982,516
Source: Office of Technology Promotion and Transfer			

Figure 1.1 Budget for Invention Project for Rural Development from 1992-2003 (OTPT, 2003)

There are two reasons for the decline. First, due to being a government sector and by focusing only on the amount of research and development in science and technology, R&D projects emphasize building up the capability of manpower in science and technology only. This is because, in early 1991, there were a small number of researchers in the area of science and technology (Tuntraporn, 2003).

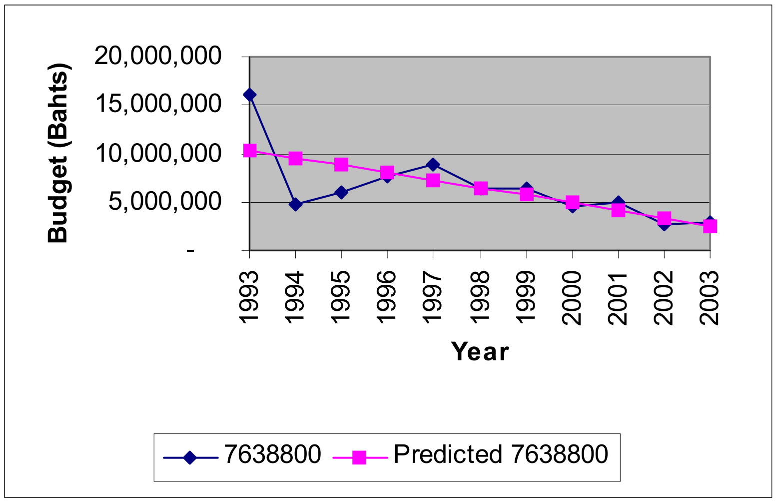


Figure 1.2 Trends of Budgets

Secondly, after the economic crisis in 1998, OTPT faced the new challenge of R&D projects not meeting the requirements of productivity. Then, the budget was decreased and showed a negative trend as seen in Figure 1.2

In order to bring the R&D projects to the business units, this study will use supply chain management as strategic planning, and the research of abalone farming as a feasibility study.

1.2 Problem Statement

Design a supply chain system for abalone to turn abalone farming into a successful commercial industry.

1.3 Present Situation

1.3.1 Global Trend. Many countries in the world such as Japan, Australia, New Zealand, and Mexico as shown in Figure 1.3 produce abalone in farms. Japan and Australia had the largest market share in 1989; they produced more than 5000 tons. But ten years later, farmers in Japan had decreased their production by half while farmers in Australia maintained their own production and still kept on increasing.

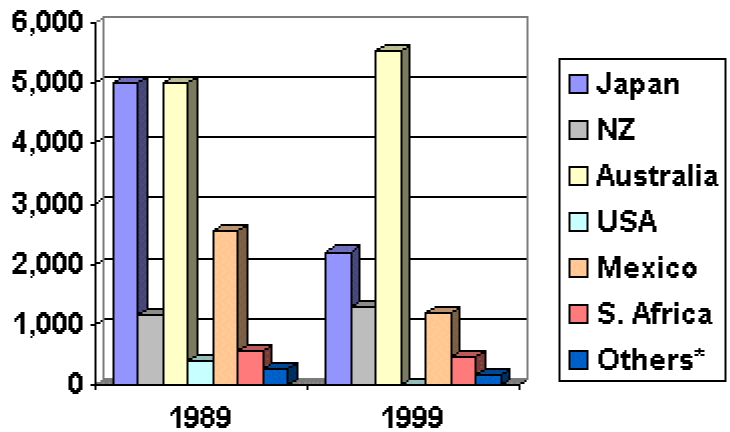


Figure 1.3 Abalone Raising Farms (Bogard Design, 2003)

It has been estimated that the demand of abalone in the world market should be 5000 tons over the supply in the years 2004, as shown in Figure 1.4.

1.3.2 Local Trend. Tourism and food industries are promoted by the Thai government because they bring a lot of income and have faster growth rates than other sectors, so it is a good opportunity to produce this kind of product in order to introduce to the markets. The native abalone can be found in three species, *Haliotis asinina*, *Haliotis ovina* and *Haliotis varia*.

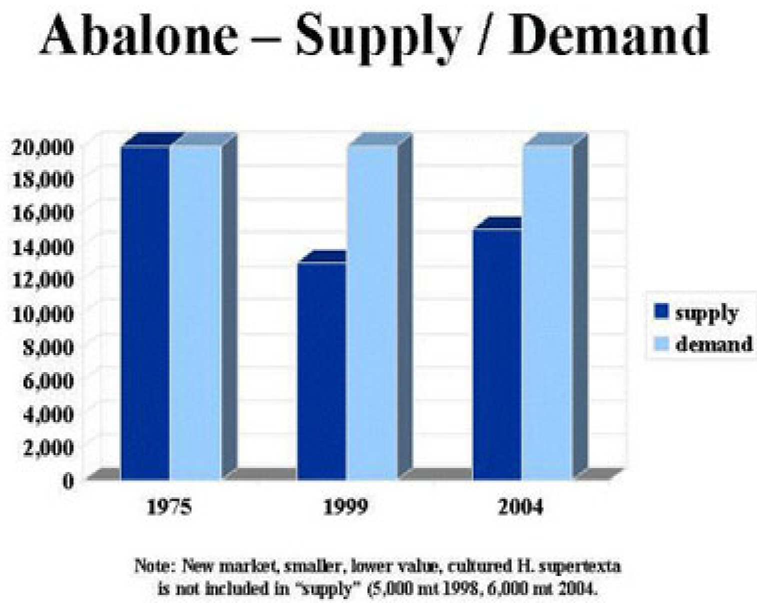


Figure 1.4 Comparison between Demand and Supply of Abalone in the World Market, (Bogard Design, 2003).

The *Haliotis asinina* is a fast growing species which is widely found in the Gulf of Thai, East Coast of Thailand, and Andaman Sea, West Coast of Thailand.

Since 1988, Department of Fishery, Ministry of Agriculture and Co-operative, has studied how to produce juvenile *Haliotis asinina* in mass; the model of hatchery stage was also studied, (Department of Fishery, 2002).

From 1998 to 2001, a model of farming stage was studied by Jarayabhand on the topic of the Development on Commercial Production of Cocktail Size Abalone, *Haliotis asinina* by Land Based System. The objective of this project was to focus on feasibility study, while considering factors such as abalone seeds, packaging of transportation from hatchery to customers, culture system, and cost of the small unit model. The culture system was focused on the nursery phase I and II, growing out phase, water management system, air management system, utility system, and food management system (Jarayabhand, 2001).

A model of small farming has been designed in order to grow abalone in a closed loop system which is focused on cost saving and environment protection, and to find a fixed cost, and variable cost of the system, (Jarayabhand, 2002).

From 1997 to 1998, Sahawacharin and Pumthong had studied the topic Development on Commercial Producing of Thai Abalone*, Haliotis asinina* and *Haliotis ovina* species. This project was to produce abalone seeding, and to compare between two species on the commercial scale (Sahawacharin and Pumthong, 2002).

In 2003, Tiravanit studied the topic of Realized Heritability Estimation on Growth Rate of Donkey's Ear Abalone, Haliotis asinine Linneaus 1758, as seen in Figure 1.5. The objective is to select a number of abalones, which give a fast growth rate, for reproduction (Tiravanit, S. 2003).

Figure 1.5 Abalone Land Based System (Tiravanit, 2003)

1.3.3 Production: Jarayabhand has researched a prototype of the hatchery and farm stage in order to bring the abalone to commercial scale. The prototype which gives the average yield at hatchery stage of 25000 units or seeds per month, and of farming stage at 2500 units per month has been developed. The production over time will depend on the demands in the market. In the initial stage, the production is not so high, and is expected to grow continuously. The technology transfer is focused on the farmers, who are interested in producing not only a good quality but also in preserving the environment (Jarayabhand 2002).

1.3.4 Marketing: This product is quite new in the market, and there is no competitor in the market because this technology is in the early stage of development. There are two types of products, juvenile and adult abalone. The size of juvenile abalone is 20 millimeters; the size of adult abalone is 90 to 100 millimeters.

Chapter 2

Literature Review

Supply chain is related to activities associated with moving goods from the raw materials stage through to the end user. Heizer and Render (1999) mention that supply chain management is the management of activities that procure raw materials, transform those materials into intermediate goods and final products, and deliver the products through a distribution system. These activities, including purchasing, warehousing, transportation, inventory levels, order fulfillment, sharing customer, forecasting and production information etc., are important to the relationship between suppliers and distributors. The objective of building a chain of suppliers is to reduce waste and maximize values to ultimate customer (Heizer and Render, 1999).

One can use decision models to help make decisions about the relationship among suppliers and distributors. A decision model is a mathematical model, and a linear programming model is a decision model that can be used to find relationships among suppliers and distributors. Linear programming models can be solved by the Excel program and Solver tool in order to find the decision parameters, such as costs and quantities. One can find the minimum cost of shipped costs, fixed costs, and variable costs. In quantity, we want to know how many items to ship from suppliers to distributors. Then, a supply chain system can be designed.

2.1 What is Supply Chain Management?

Definition of Supply Chain Management (SCM): "Supply chain management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements" (Simchi-Levi and Kaminsky, 2000).

To clarify this definition, two main ideas must be considered. The first idea is cost in supply chain. In making products, a network system flows from suppliers and manufacturing facilities through warehouses and distribution centers to retailer and stores, so the cost is a function that must be considered. The other idea is the firm's activities at the strategic level, tactic level, and operational level, because supply chain management circulates around an efficient integration of suppliers, manufacturers, warehouses, and stores (Simchi-Levi and Kaminsky, 2000).

2.1.1 What is different between Supply Chain Management and the logistics management?

Logistics is the operational part of the supply chain. Logistic management is concerned about the activities around the process and the flow of material in the process. The definition of logistics management given by the Council of Logistics Management (CLM) is as follows:

> "Logistics is that part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements (CLM, 2003)."

Both definitions are emphasized in the integration of the component in the supply chain.

2.1.2 Why Supply Chain Management?

Two main reasons to support SCM are information technology and strategies. First, the growth of information technology has helped to integrate business planning. Widespread implementation of enterprise resource planning (ERP) systems offers the promise of homogenous, transactional databases that will facilitate integration of supply chain activities (Shapiro, 2001).

Secondly, companies have found strategies to reduce costs and compete better in different markets. The strategies include just-in-time manufacturing, lean manufacturing, kanban, total quality management and others that are very well-known and could reduce costs effectively. So companies believe that effective supply chain management is the next step they need to take to increase profit and market share (Simchi-Levi and Kaminsky, 2000).

2.2 Decision Model

Decision model is a symbolic model with decision variables and at least one performance measure, while the symbolic model is the algebraic representation of a linear program, (Moore and Weatherford, 2001).

A model is a tool that a manager uses to solve the problem in a scientific way. For example, when a manager is facing a situation involving conflicting or competing alternatives, the situation is analyzed and decisions are made in order to resolve the conflicts or competing alternatives. After implementing the decision, the organization receives the payoff as shown in Figures 2.1 and 2.2 (Moore and Weatherford, 2001).

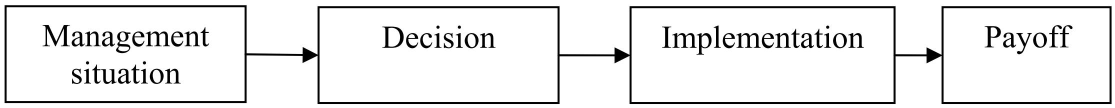


Figure 2.1 Managerial approach to decision making (Moore and Weatherford, 2001).

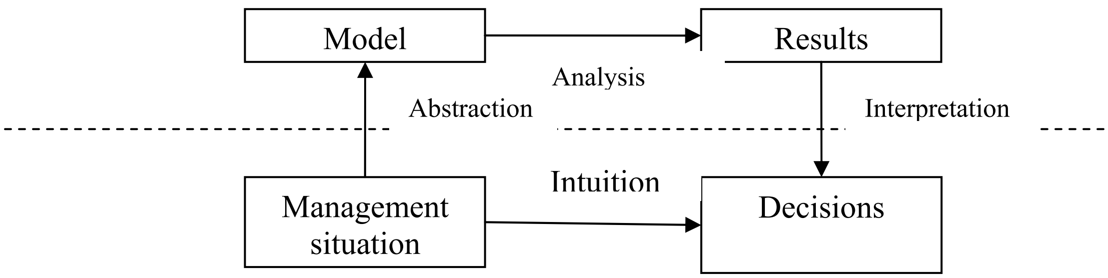


Figure 2.2 Modeling Process (Moore and Weatherford, 2001).

After building the model, it is analyzed in order to generate some results or conclusions derived from the model. Then, the results are interpreted based on the model, and then on to decisions.

2.3 Linear programming

Moore and Weatherford (2001) provide the definition of linear programming as follows:

"Linear program (LP) is a deterministic model consisting of linear equations and a single performance measure (objective function) to be optimized subject to satisfaction of a given set of constraints."

Every linear program has a linear objective function that represents the performance measure to be either maximized or minimized.

A constraint is a mathematical inequality (an inequality constraint) or equality (an equality constraint) that must be satisfied by the variables in the model. Inequality constraints are constraints requiring some function on the decision variables in a model to be ≥ (greater than or equal to) or ≤ (less than or equal to) a constant.

Decision variables are the variables under the decision maker's control. These are the variables that appear in the models that we have formulated in LP mode (Moore and Weatherford, 2001).

2.3.1 Constraint function

The constraint function is the left hand side (LHS) of the constraint. It depends on the decision variables, (Moore and Weatherford, 2001). The right-hand side is the number of a constraint.

2.3.2 Objective function

Objective function represents the performance measure to be either maximized or minimized. For example, the portfolio manager may want to maximize the return on the portfolio; the manager may want to satisfy the demand at minimum production cost. So, the performance measure to be optimized is called the objective function.

2.4 Linear function and integer program

A linear function is a function in which each variable appears in a separate term. There are no powers other than one, and there are no logarithmic, exponential, IF () statements or trigonometric terms, (Moore and Weatherford, 2001).

One of the characteristics of the linear function is a straight line; when plotting a linear function graph, a linear function will give a straight-lined graph. A linear function has one or more than one variables with coefficients, such as $Y = A + BX$, or $Y = A_1X_1 + A_2X_2 + A_3X_3 + A_nX_n$ where X, X_1, X_2 …. ,and X_n are variables, and A, B, A_1, A_2 …. , and A_n are coefficients.

Integer program is a model in which one or more variables can have only integer values, (Moore and Weatherford, 2001).

LP has linear functions, so it can be solved efficiently. But integer problems take much longer to solve.

2.5 Transportation Model

Transportation model is an LP model to find the least expensive way of satisfying demands at *n* destinations with supplies from *m* origins. The destination is a node in a network with positive demand, and origin is a node in a network with positive supply, (Moore and Weatherford, 2001). In this model, management must decide how to send products from various sources (e.g. hatchery or farm sites) to various destinations (e.g. farm sites or customer's stores) in order to satisfy requirements at the lowest possible cost.

2.6 Solver

Solver is a spreadsheet add-in program that can optimize the spreadsheet representation of an LP model. The technique that is used in the Solver is called a mathematical programming algorithm which efficiently finds the optimal decisions for a given spreadsheet model. An algorithm is simply a computer code that follows an iterative recipe for finding optimal decisions. Solver can optimize both linear and nonlinear models (Moore and Weatherford, 2001).

Using Solver:

Start Excel.

1. Optimize it by choosing the Solver.
2. The Solver add-in and its optimization module will be loaded into memory. When the loading is finished, Solver brings up a dialog box to collect information for the optimization process.
3. After specifying which cell contains the objective function formula to be optimized and which cells contain decision variables, then, click the Solve button.
4. Solver will translate the model and carry out the optimization process.
5. Assuming there are no errors in the spreadsheet LP model, Solver will bring up a Solver Results dialog box in which reports can be requested and have Solver update the original model with the optimal decision cell value. It creates each request report on a separate worksheet in the Excel workbook.
6. At this point, we are in a position to continue “What if” projection.

Steps in using Solver are shown in Figure 2.3 (Moore and Weatherford, 2001).

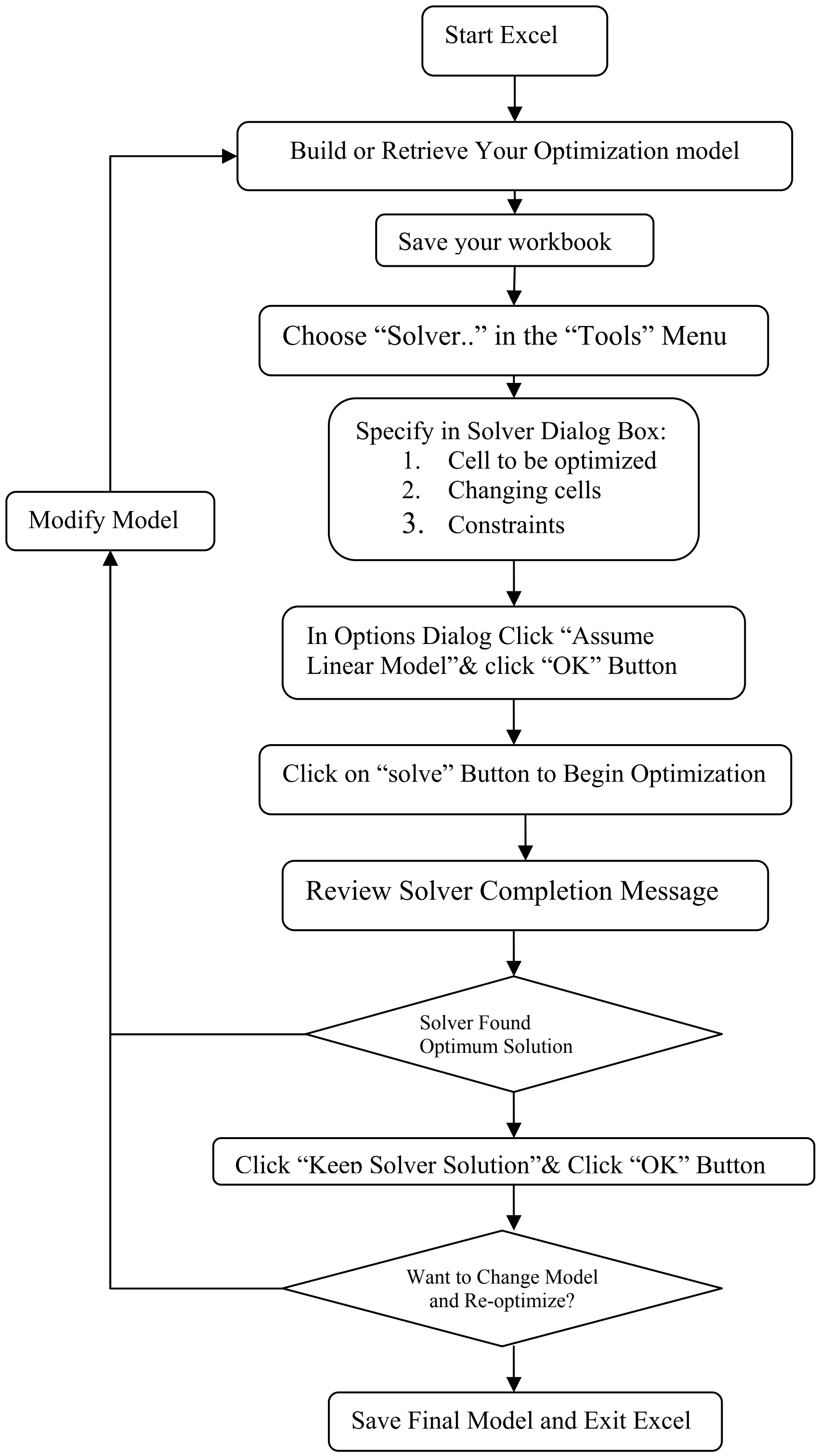


Figure 2.3 Solver Flowchart

2.7 Design supply chain system

The idea of strategic planning for abalone farms and hatcheries by using supply chain management is to consider which hatchery and how much abalone should be shipped to farms, which farms to ship abalone to the customers, what routes to take, and how much to carry per route. Linear programming and integer programming models will be selected to solve the linear function model. After setting the model, Solver will be used to optimize linear model. As shown in Figure 2.4, the decision is the minimum transportation cost, decision variables are number of units from farm and hatchery to ship to the customers; the demand from customers and supply from the hatcheries or farms are constraints.

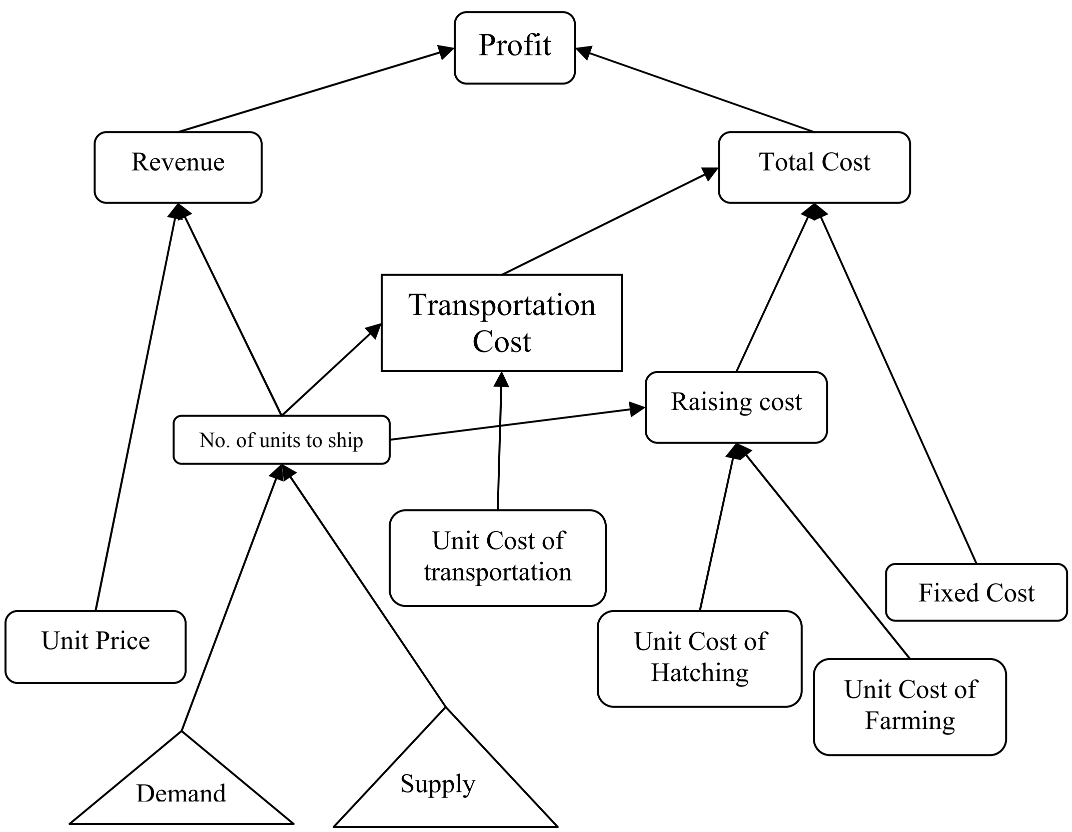


Figure 2.4 Transportation Model of Abalone's Farm and Hatchery

2.8 Basic Transportation Model

Transportation model is a linear optimization model in which management must determine how to send products from various sources (e.g. warehouse) to various destinations (e.g. customer) in order to satisfy requirements at the lowest possible cost.

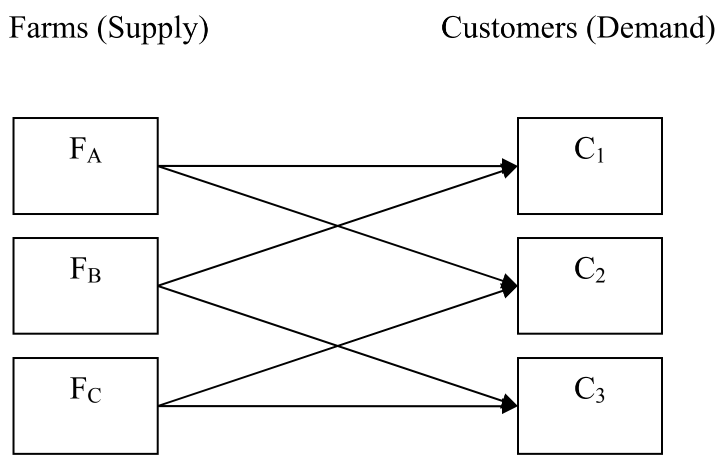


Figure 2.5 Transportation Problem

For example, Figure 2.5, assumes that there are three farms, F_A F_B and F_C, and the capacity of each farm is 25000 seeds. If there are three customers, C_1 C_2 and C_3, the demand for each customer is as follows:

Customer	Demand
C_1	40000
C_2	20000
C_3	10000

Assume the cost of shipment of one unit from farms to customers is as follows:

Farm	C_1	C_2	C_3
F_A	10	20	15
F_B	12	18	16
F_C	11	14	13

The goal is to minimize the total cost of transportation from farms to customers. The formulation of this program is

X_{ij} = number of product sent from farm i to customer j

i= A, B, C

j= 1, 2, 3

X_{11} is the number of product sent from farm F1, to customer C1. With this definition, the total transportation cost becomes

$10X_{A1} + 20X_{B2} +$ ----$+13X_{C3}$

The decision variable:

Number of units to ship from farm i to customer j.

$X_{A1,}$ X_{A2}, ……., X_{C3}

Objective:

Minimize cost of shipping

Min. $\sum T_{ij} X_{ij}$ where T = cost/unit for each route; i = A, B, C; j= 1, 2, 3

Constraints:

Total number of unit shipped is less than or equal to supply for each farm

$\sum$number of unit shipped $\leq$ supply for each farm (25000).

Total number of unit shipped is greater than or equal to demand for each customer.

$\sum$number of unit shipped $\geq$ demand for each customer (40000, 20000, and 10000 respectively)

Then the model's formula is as follows.

Objective:

Min. $[10X_{A1}+20X_{A2}+ \dots\dots\dots XC3]$

Subject to constraints:

Supply side

$X_{A1} + X_{A2} + X_{A3} \leq 25000$

$X_{B1} + X_{B2} + X_{B3} \leq 25000$

$X_{C1} + X_{C2} + X_{C3} \leq 25000$

Demand side

$X_{A1} + X_{B1} + X_{C1} \geq 40000$

$X_{A2} + X_{B2} + X_{C2} \geq 20000$

$X_{A3} + X_{B3} + X_{C3} \geq 10000$

2.8.2 Solver

From mathematical model, we transform to Excel program as in Figure 2.6.

	A	B	C	D	E	F	G
1		**C1**	**C2**	**C3**	**total**		**Supply**
2	**FA**				0	<=	25000
3	**FB**				0	<=	25000
4	**FC**				0	<=	25000
5	Total	0	0	0			
6		>=	>=	>=			
7	**Demand**	40000	20000	10000			
8							
9	**Shipping Cost**						
10		**C1**	**C2**	**C3**			
11	**FA**	10	20	15			
12	**FB**	12	18	16			
13	**FC**	11	14	13			
14							
15	**Transportation cost**			0			

Figure 2.6 Transportation Model in Excel Program

Formulas in the Excel program are shown in Figure 2.7, for example, in transportation cost, we use SUMPRDUCT ().

	C1	C2	C3	total		Supply
FA				=SUM(B2:D2)	<=	25000
FB				=SUM(B3:D3)	<=	25000
FC				=SUM(B4:D4)	<=	25000
Total	=SUM(B2:B4)	=SUM(C2:C4)	=SUM(D2:D4)			
	>=	>=	>=			
Demand	40000	20000	10000			
Shipping Cost						
	C1	C2	C3			
FA	10	20	15			
FB	12	18	16			
FC	11	14	13			
Transportation cost		=SUMPRODUCT(B2:D4,B11:D13)				

Figure 2.7 Formula in Excel Program

Using Solver to solve the problem, we find the minimum transportation cost. In order to use Solver in Excel program, we select Tools bar menu. After selecting Solver, it shows Solver Parameter Box as shown in Figure 2.8. In Set Target Cell, click cell C15; in By Changing Cell, click cell B2 through D4, so it will show \$B\$2:\$D\$4; in Subject to the Constraints, click Add box then enter as follow:

\$B\$5:\$D\$5 >= \$B\$7:\$D\$7

$E$2:$E$4 >= $G$2:$G$4

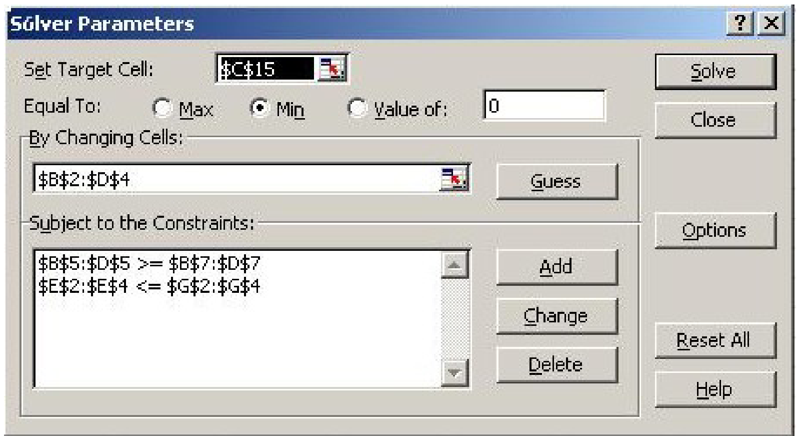


Figure 2.8 Solver Parameters Box

Click Options button, then it will show Solver Options as shown in Figure 2.9; click Assume Linear Model and Assume Non-Negative. Click OK button. It will go back to Solver Parameters Box.

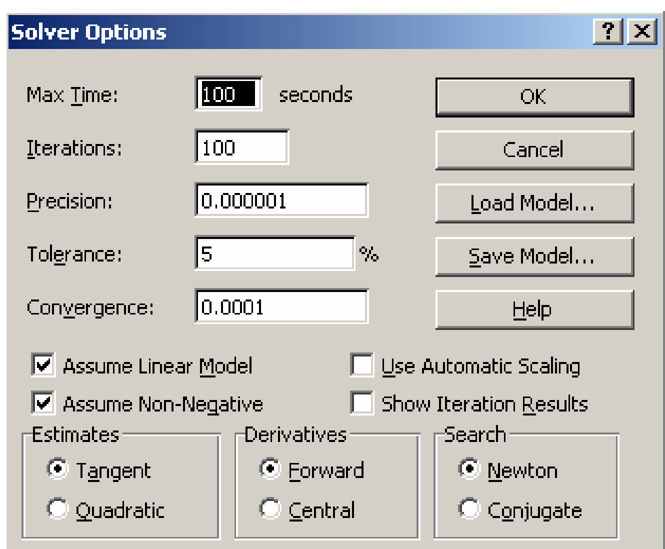


Figure 2.9 Solver Options Box

Click Solve button. It will go to Solver Results as shown in Figure 2.10. Then, click OK button, it will show solution as shown in Figure 2.11.

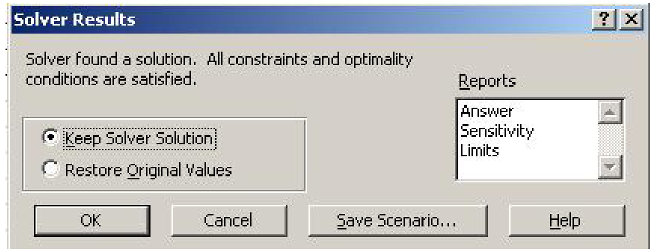


Figure 2.10 Solver Results

	C1	C2	C3	Total		Supply
FA	25000	0	0	25000	<=	25000
FB	15000	0	5000	20000	<=	25000
FC	0	20000	5000	25000	<=	25000
Total	40000	20000	10000			
	>=	>=	>=			
Demand	40000	20000	10000			
Shipping Cost						
	C1	**C2**	**C3**			
FA	10	20	15			
FB	12	18	16			
FC	11	14	13			
Transportation cost		855000				

Figure 2.11 Solution of the Transportation Model

Chapter 3

Methodology

This study uses transportation model as a tool to solve the problems in supply chain design for abalone farming in Thailand. The operation in abalone farming has two main products: hatchery size abalone and farm size abalone. The first product, hatchery size abalone, grows 0 to 10 or 20 millimeter (mm) in shell length. The second product, farm size abalone, grows 10 or 20 mm. to 100 mm or more in shell length as shown in Figure 3.1.

Abalone Products	
Length of shell (mm)	**Product Type**
0 - 10 or 20	Hachery size
10 or 20 - 100 or more	Farm size

Figure 3.1 Abalone Products

The first products grown in the hatchery will be shipped from hatcheries to farms, and the second products, grown in farms, will be shipped from farms to customers as shown in Figure 3.2. The amount of abalone shipped from farm to customer and the amount of abalone hatcheries should supply to farms depends on demand from customers.

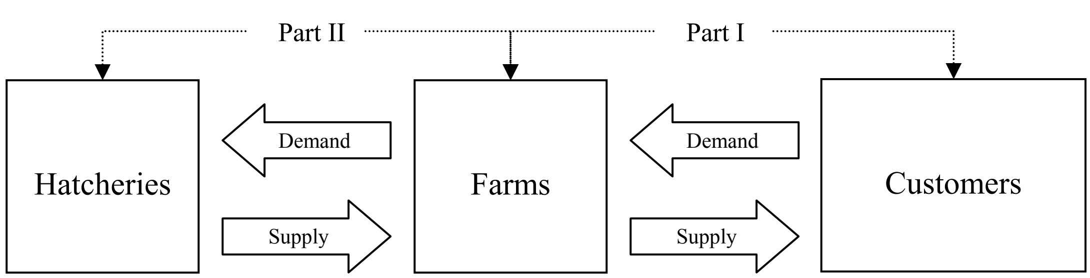


Figure 3.2 Abalone Supply Chain

Then, the steps in solving these problems are as follows:

1. Data gathering
2. Setting up two transportation models
3. Excel solution
4. Set up various demands

Step I. Data Gathering

Data input into these transportation models are demands, supplies, and costs. Demand comes from customers; supplies are from hatcheries and farms. Costs are fixed cost, variable cost and shipped cost. Fixed cost and variable cost are from hatcheries and farms; and unit of transportation costs are costs from shipping of goods from hatcheries to farms and from farms to customers.

Step II. Set two models

In this problem, supply chain is composed of four hatcheries, thirteen farms, and eleven customers. These parameters will be decision variables in the transportation model solved by Solver program. Because there are many decision variables, and more than 200 parameters, the Solver program cannot run the program properly. Therefore, the transportation model must be separated into two parts.

In transportation model part I, the problem will be solved between farms and customers in order to find the minimum transportation cost by fixing the number of farms.

In transportation model part II, the problem will be solved between hatcheries and farms in order to find minimum transportation cost by fixed number of hatcheries.

Step III Excel Solution

Solutions of transportation models are costs, and activities in the network system of supply chain. Each scenario shows different costs including minimum shipped costs, fixed costs and variable costs. Activities are the quantity of abalone to ship from hatcheries to farms and from farms to customers, which hatchery should be opened, which farm should be opened, and the quantity of abalone to be grown in each farm or hatchery.

Step IV. Set up various demands.

Demands are classified into three categories, small, medium, and large demand. One scenario is selected in small demand, and two scenarios are selected in medium and large demand.

Chapter 4

Transportation Model

4.1 Data of the abalone farming in Thailand

Assumptions

1. The local Thai consumers demand should be 5 to 10% of global demand.
2. Hatcheries and farms are located in the provinces that are close to the sea because they need sea water with high salinity i.e. around 33 ppt., pH around 8.0-8.3 (Bogart Designs, 2003).
3. Hatchery and farming sites can be located in the same province, but fewer hatchery sites are required than farming sites due to the fact that hatcheries can produce large volume, and can support many farming sites.
4. Fixed cost and variable cost are based on the R& D project (Department of Fishery, 2002, and Jarayabhand, 2002)
5. The production capacity of hatchery and farm use the minimum percent of survival rate from prototype's experiment.

4.1.1 Forecast demands

Given that the capacity of local consumers in Thailand is 228 tons per year or 19 tons per month as shown in Figure 4.1 and by assuming that big cities have large numbers of population and customers, therefore, demand in big cities is larger than small cities. In addition, these cities are well known for tourists, and have a lot of good seafood restaurants. So, it is a good opportunity for abalone industry to contribute to these markets, and demand will go up to meet this forecast in the future.

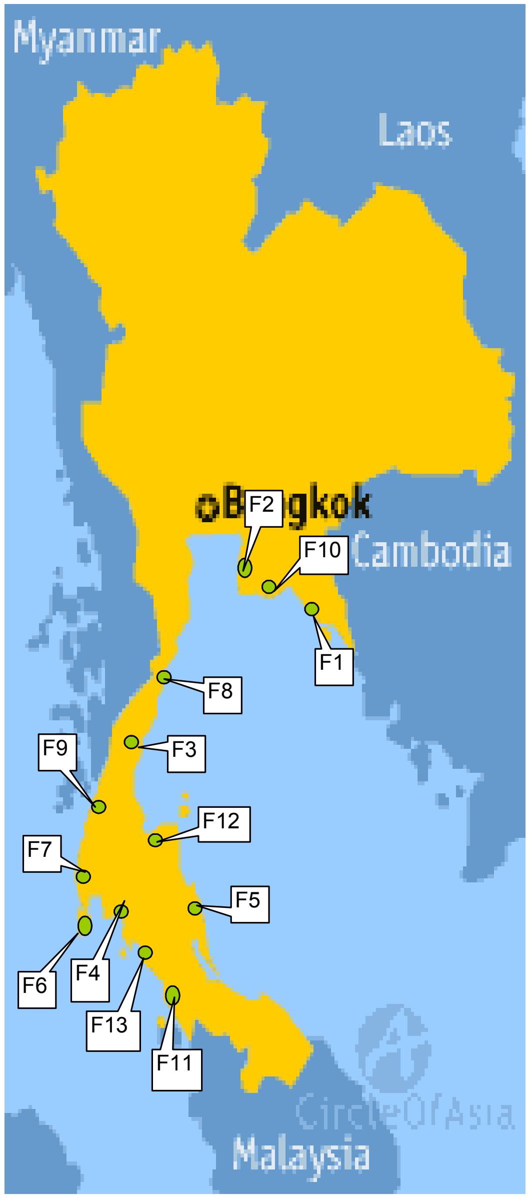
				Unit per Month	
	Customer Demand	Kg per week	Kg. per Month	Min.	Max.
1	Bangkok	1250	5000	50000	250000
2	Changmai	250	1000	10000	50000
3	Changrai	625	2500	25000	125000
4	Khonkaen	375	1500	15000	75000
5	Nakhon Ratchasima	250	1000	10000	50000
6	Nakhon Si Thumarat	250	1000	10000	50000
7	Nakornsawan	250	1000	10000	50000
8	Phuket	500	2000	20000	100000
9	Saraburi	375	1500	15000	75000
10	Songkhla	375	1500	15000	75000
11	Surat-Thani	250	1000	10000	50000
	Total	4750	19000	190000	950000

Figure 4.1 Forecast Demand of Abalone's Product in Thailand

4.1.2 Supplies of hatchery and farm

Farms are located along both the east coast and west coast of Thailand because they need sea water. Selected provinces in the east coast are Chantaburi, Chonburi, Chumporn, Nakhon Si Thummarat, Prachuap Khirikhan, Rayong, Surat-Thani, and selected provinces in the west coast are Krabi, Phang-nga, Phuket, Ranong, Satun, and Trang as shown in figure 4.2. The estimated capacity of each farm is 25,000 units per month. Because hatcheries can produce a large volume of abalone units, so, the estimated capacity of each hatchery is 75,000 units per month (Jarayabhand, 2002).

The locations of hatcheries are in Chonburi, Krabi, Prachuop Khirikhan, and Satun as shown in Figure 4.3.



Locations		
	F1	Chantaburi
H1	F2	Chonburi
	F3	Chumporn
H2	F4	Krabi
	F5	Nakornsrithumarat
	F6	Phuket
	F7	Phung-nga
H3	F8	Prachuap Khirikhan
	F9	Ranong
	F10	Rayong
H4	F11	Satun
	F12	Surathani
	F13	Trang

Figure 4.2 Location of Abalone farms in Thailand

	Supply sites	Raising sites Unit per Month	Hatchery sites Unit per Month
1	Chantaburi	25000	
2	Chonburi	25000	100000
3	Chumphon	25000	
4	Krabi	25000	75000
5	Nakhon Si Thammarat	25000	
6	Phang-nga	25000	
7	Phuket	25000	
8	Prachuap Khirikhan	25000	75000
9	Ranong	25000	
10	Rayong	25000	
11	Satun	25000	75000
12	Surat-Thani	25000	
13	Trang	25000	
	Total	325000	325000

Figure 4.3 Lists of Hatcheries and Farms

4.1.3 Fixed cost and variable cost

The prototype of hatchery stage studied by Department of Fishery (2002) in order to find investment costs, found that the fixed cost was 12,081 Baht per month and variable cost was 27,068 Baht per month, see details in appendix A (Department of Fishery, 2002)

The prototype of farm stage studied by Jarayabhand (2002) in order to find investment cost, found that the fixed cost was 18,205 Baht per month and the variable cost was 79.049 Baht per month, see details in appendix B, (Jarayabhand, 2002).

4.1.4 Shipped Cost

There are three parameters involved in calculating the shipped cost, load, distance and cost of shipment per unit.

First, one ton of hatchery size abalone is 40,000 units, and one ton of farm size abalone is 10,000 units. Second, to find a distance between hatchery and farm, and distance between farm and customer, there is a software program to calculate distance from one city to others. Consequently, the summary data of distances from hatcheries to farms are shown in Figure 4.4, and the summary data of distances from farms to customers are shown in Figure 4.5 (AURAM Siam, 2002).

	Chantaburi	Chonburi	Chumphon	Krabi	Nakhon Si Thammarat	Phang-nga	Phuket	Prachuap Khirikhan	Ranong	Rayong	Satun	Surat-Thani	Trang	
Chonburi	146	0	544	895	861	869	943	362	549	98	1054	725	909	H1
Krabi	1059	895	363	0	233	86	176	534	296	993	276	211	131	H2
Prachaub	526	362	183	534	500	508	582	0	288	460	693	364	548	H3
Satun	1218	1054	523	276	233	366	453	693	549	1152	0	372	140	H4
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	

Figure 4.4 Distances -Hatchery to Farm

Location	**Bangkok**	**Changmai**	**Changrai**	**Khonkaen**	**Nakhon Ratchasima**	**Nakornsawan**	**Nakhon Si Thumarat**	**Phuket**	**Saraburi**	**Songkhla**	**Surat-Thani**	
Chantaburi	245	941	1030	649	332	485	1025	1107	313	1195	889	F1
Chonburi	81	777	866	530	280	321	861	943	201	1031	725	F2
Chumphon	463	1159	1248	912	722	703	330	412	570	500	193	F3
Krabi	814	1510	1599	1263	1073	1054	233	176	921	313	211	F4
Nakhon Si Thammarat	780	1476	1565	1229	1039	1020	0	336	887	161	134	F5
Phang-nga	788	1484	1573	1237	1047	1028	245	87	895	403	196	F6
Phuket	862	1558	1647	1311	1121	1102	336	0	969	494	287	F7
Prachuap Khirikhan	281	977	1066	730	540	521	500	582	388	670	364	F8
Ranong	568	1264	1353	1017	827	808	356	300	675	525	219	F9
Rayong	179	875	964	628	345	419	959	1041	272	1129	823	F10
Satun	973	1669	1758	1422	1232	1213	233	453	1080	125	372	F11
Surat-Thani	644	1340	1429	1093	903	884	134	287	751	304	0	F12
Trang	828	1524	1613	1277	828	1068	123	312	935	176	226	F13
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	

Figure 4.5 Distances - Farm to Customer

Third, to find cost of shipment per unit depends on the type of transportation such as, truck, train, air or ship, etc. In this case, due to the load of abalone, the maximum load of a farm is 2.5 tons, so four wheel trucks should be used for the transportation.

From the case study of transportation in Thailand, the costs of seafood shipped live by truck are classified into three categories, short range, medium range, and long range, as shown in Figure 4.6.

Truck Cost	Km.	Baht/ton-km
Short distance	0-100	8.76
Medium distance	100-400	4.04
Long distance	more than 400	4.37

Figure 4.6 Transporatation Cost by 4 Wheel Truck

The distance of short range was 1 to 100 kilometers (km); the distance of medium range 101 to 400 km; the distance of long range more than 400km. The shipped cost was 8.76 Baht/ ton-km for short range, 4.04 Baht/tom-km for medium range, and 4.37 Baht/ton-km for long range, (Institute of Intellectual Property of Chulalongkorn University, 2001).

Consequently, the shipped cost can be calculated from the cost of one unit of shipping multiplied by the distance between origin and destination. For example, the cost of one unit from Chonburi to Chantaburi is 4.04 Baht/ton-km; the distance between the two cities is 146 km; one ton of hatchery abalone is 40000 units. Therefore, the shipped cost is 4.04 x 146/ 40000 or 0.0147 Baht per unit. In this way, the summary of the calculated data is shown in Figure 4.7 for the shipped cost of hatchery and farm, and Figure 4.8 for the shipped cost of farm and customer.

	Chantaburi	Chonburi	Chumphon	Krabi	Nakhon Si Thammarat	Phang-nga	Phuket	Prachuap Khirikhan	Ranong	Rayong	Satun	Surat-Thani	Trang	
Chonburi	0.01	0.00	0.06	0.10	0.09	0.09	0.10	0.04	0.06	0.02	0.12	0.08	0.10	H1
Krabi	0.12	0.10	0.04	0.00	0.02	0.02	0.02	0.06	0.03	0.11	0.03	0.02	0.01	H2
Prachaub	0.06	0.04	0.02	0.06	0.05	0.06	0.06	0.00	0.03	0.05	0.08	0.04	0.06	H3
Satun	0.13	0.12	0.06	0.03	0.02	0.04	0.05	0.08	0.06	0.13	0.00	0.04	0.01	H4
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	

Figure 4.7 Shipped Costs - Hatcheries to Farms

Location	**Bangkok**	**Changmai**	**Changrai**	**Khonkaen**	**Nakhon Ratchasima**	**Nakornsawan**	**Nakhon Si Thumara**	**Phuket**	**Saraburi**	**Songkhla**	**Surat-Thani**	
Chantaburi	0.10	0.41	0.45	0.28	0.13	0.21	0.45	0.48	0.13	0.52	0.39	F1
Chonburi	0.07	0.34	0.38	0.23	0.11	0.13	0.38	0.41	0.08	0.45	0.32	F2
Chumphon	0.20	0.51	0.55	0.40	0.32	0.31	0.13	0.18	0.25	0.22	0.08	F3
Krabi	0.36	0.66	0.70	0.55	0.47	0.46	0.09	0.07	0.40	0.13	0.09	F4
Nakhon Si Thammarat	0.34	0.65	0.68	0.54	0.45	0.45	0.00	0.14	0.39	0.07	0.05	F5
Phang-nga	0.34	0.65	0.69	0.54	0.46	0.45	0.10	0.08	0.39	0.18	0.08	F6
Phuket	0.38	0.68	0.72	0.57	0.49	0.48	0.14	0.00	0.42	0.22	0.12	F7
Prachuap Khirikhan	0.11	0.43	0.47	0.32	0.24	0.23	0.22	0.25	0.16	0.29	0.15	F8
Ranong	0.25	0.55	0.59	0.44	0.36	0.35	0.14	0.12	0.29	0.23	0.09	F9
Rayong	0.07	0.38	0.42	0.27	0.14	0.18	0.42	0.45	0.11	0.49	0.36	F10
Satun	0.43	0.73	0.77	0.62	0.54	0.53	0.09	0.20	0.47	0.05	0.15	F11
Surat-Thani	0.28	0.59	0.62	0.48	0.39	0.39	0.05	0.12	0.33	0.12	0.00	F12
Trang	0.36	0.67	0.70	0.56	0.36	0.47	0.05	0.13	0.41	0.07	0.09	F13
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	

Figure 4.8 Shipped Costs – Farms to Customers

4.2 Transportation Models

Because of too many decision variables, the Solver program can not run properly, thus this problem is separated into two parts. In transportation model part I, we will find a minimum transportation cost where abalone is shipped from farms to customers. Decision variables are number of abalone shipped from each farm to each customer and farms to open. Constraints are demand from each customer and supply from each farm.

In transportation model part II, we will find a minimum transportation cost where abalone is shipped from hatcheries to farms. Decision variables are number of abalone shipped from each hatchery to each farm and hatcheries to open. Constraints are demand from each farm, and supply from each farm. The amount of demand of farm in Part II is the amount of supply of farms which was solved by program from Part I.

4.2.1 Formulation of Transportation Model Part I

Assume given data are as follows: there are 11 farms to supply abalones to customers, each supply can offer 25,000 units, and total demand from customers is 70,000 units and demands from customers C1 through C11 are 25000, 0, 0, 0, 0, 0, 0, 15000, 0, 15000, and 15000 units, respectively. Thus, three farms should be opened.

The model's formulation is as follows:

Objective:

$$\text{Min. } [.01X_{F1,C1} + .41X_{F1,C2} + \ldots\ldots\ldots X_{F13,C11}]$$

Where $X_{F1,C1}, X_{F1,C2}, \ldots\ldots X_{F13,C11}$ are decision variables;

F1, F2, ……, F13 are farms

C1, C2, ……, C11 are customers

Subject to constraints:

Supply side: if each supply is 25000, right hand side (RHS) will be 25000.

$$X_{F1,C1}+X_{F1,C2}+\ldots+X_{F1,C11} \leq 25000$$

$$X_{F2,C1}+X_{F2,C2}+\ldots+X_{F2,C11} \leq 25000$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$X_{F13,C1}+X_{F13,C2}+\ldots+X_{F13,C11} \le 25000$$

Demand side: demands are 25000, 0, 0, 0, 0, 0, 0, 15000, 0, 15000, and 15000; then, RHS is equal to these demands.

$$X_{F1,C1}+X_{F2,C1}+\ldots.+X_{F13,C1} \ge 25,000$$

$$X_{F1,C2}+X_{F2,C2}+\ldots.+X_{F13,C2} \ge 0$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$X_{F1,C11}+X_{F2,C11}+\ldots+X_{F13,C11} \ge 15,000$$

To solve this problem with Excel program, data input are as follows:

1. We transform these formulas into Excel program as shown in Figure 4.9.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total			Capacity	y/n
F1												0	<=	0	25000	
F2												0	<=	0	25000	
F3												0	<=	0	25000	
F4												0	<=	0	25000	
F5												0	<=	0	25000	
F6												0	<=	0	25000	
F7												0	<=	0	25000	
F8												0	<=	0	25000	
F9												0	<=	0	25000	
F10												0	<=	0	25000	
F11												0	<=	0	25000	
F12												0	<=	0	25000	
F13												0	<=	0	25000	
Total	0	0	0	0	0	0	0	0	0	0	0	0				0
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
Demand	25000	0	0	0	0	0	0	15000		15000	15000	70000				3

Cost of transportation from farming to customers (Baht/unit)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
F1	0.10	0.41	0.45	0.28	0.13	0.21	0.45	0.48	0.13	0.52	0.39
F2	0.07	0.34	0.38	0.23	0.11	0.13	0.38	0.41	0.08	0.45	0.32
F3	0.20	0.51	0.55	0.40	0.32	0.31	0.13	0.18	0.25	0.22	0.08
F4	0.36	0.66	0.70	0.55	0.47	0.46	0.09	0.07	0.40	0.13	0.09
F5	0.34	0.65	0.68	0.54	0.45	0.45	0.00	0.14	0.39	0.07	0.05
F6	0.34	0.65	0.69	0.54	0.46	0.45	0.10	0.08	0.39	0.18	0.08
F7	0.38	0.68	0.72	0.57	0.49	0.48	0.14	0.00	0.42	0.22	0.12
F8	0.11	0.43	0.47	0.32	0.24	0.23	0.22	0.25	0.16	0.29	0.15
F9	0.25	0.55	0.59	0.44	0.36	0.35	0.14	0.12	0.29	0.23	0.09
F10	0.07	0.38	0.42	0.27	0.14	0.18	0.42	0.45	0.11	0.49	0.36
F11	0.43	0.73	0.77	0.62	0.54	0.53	0.09	0.20	0.47	0.05	0.15
F12	0.28	0.59	0.62	0.48	0.39	0.39	0.05	0.12	0.33	0.12	0.00
F13	0.36	0.67	0.70	0.56	0.36	0.47	0.05	0.13	0.41	0.07	0.09

F	25000	Transportation Cost	0
H	75000		

Figure 4.9 Transportation Model using Excel Program- Farm to Customer

The transportation cost is the sum product of the quantity that each farm shipped to each customer and the unit cost of each farm that shipped to each customer. In this case, a SUMPRODUCT function is being used. For example, in cell G41, a transportation cost is SUMPRODUCT (B2:L14, B24:L36).

2. Using Solver to solve the problem, add Solver into Excel program, and click Solver in order to input parameters into Solver parameters box, as shown in Figure 4.10.

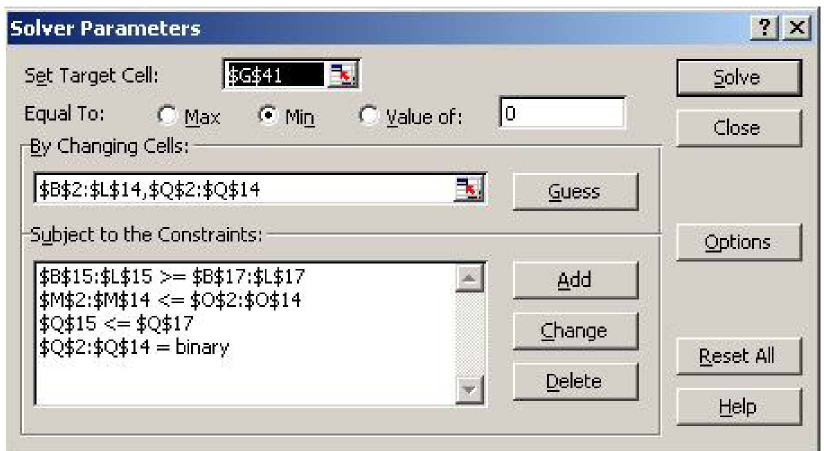


Figure 4.10 Solver Parameters Box – Farms to Customers

In Solver Parameters box, we input parameters as follow:

Set Target Cell: G41

Equal To: min.

By Changing Cells: $B$2:$L$14, Q:$Q$14

Subject to the Constraints:

$B$15:$L$15 >=$B$17:$L$17

$M$2:$M$14 <= $Q$2:$Q$14

$Q$15 <= $Q$17

Q:$Q$14 = binary

3. Click option button to set assume linear model and assume non-negative option, then click OK. It goes back to Solver Parameters.

4. Click Solve button; it goes to Solver Results. Solver gives the solution that satisfies all constraints and optimality conditions. Click OK.

5. The solution as shown in Figure 4.11 is as follow:

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total			Capacity	y/n
F1	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.9E-12	25000	0
F2	25000	0	0	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1
F3	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F4	0	0	0	0	0	0	0	0	0	0	0	0	<=	-5E-28	25000	-0
F5	0	0	0	0	0	0	0	0	0	15000	10000	25000	<=	25000	25000	1
F6	0	0	0	0	0	0	0	0	0	0	0	0	<=	-8E-13	25000	-0
F7	0	0	0	0	0	0	0	15000	0	0	5000	20000	<=	25000	25000	1
F8	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F9	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F10	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F11	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F12	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F13	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
Total	25000	0	0	0	0	0	0	15000	0	15000	15000	70000				3
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
Demand	25000	0	0	0	0	0	0	15000		15000	15000	70000				3

Cost of transportation from farming to customers (Baht/unit)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
F1	0.10	0.41	0.45	0.28	0.13	0.21	0.45	0.48	0.13	0.52	0.39
F2	0.07	0.34	0.38	0.23	0.11	0.13	0.38	0.41	0.08	0.45	0.32
F3	0.20	0.51	0.55	0.40	0.32	0.31	0.13	0.18	0.25	0.22	0.08
F4	0.36	0.66	0.70	0.55	0.47	0.46	0.09	0.07	0.40	0.13	0.09
F5	0.34	0.65	0.68	0.54	0.45	0.45	0.00	0.14	0.39	0.07	0.05
F6	0.34	0.65	0.69	0.54	0.46	0.45	0.10	0.08	0.39	0.18	0.08
F7	0.38	0.68	0.72	0.57	0.49	0.48	0.14	0.00	0.42	0.22	0.12
F8	0.11	0.43	0.47	0.32	0.24	0.23	0.22	0.25	0.16	0.29	0.15
F9	0.25	0.55	0.59	0.44	0.36	0.35	0.14	0.12	0.29	0.23	0.09
F10	0.07	0.38	0.42	0.27	0.14	0.18	0.42	0.45	0.11	0.49	0.36
F11	0.43	0.73	0.77	0.62	0.54	0.53	0.09	0.20	0.47	0.05	0.15
F12	0.28	0.59	0.62	0.48	0.39	0.39	0.05	0.12	0.33	0.12	0.00
F13	0.36	0.67	0.70	0.56	0.36	0.47	0.05	0.13	0.41	0.07	0.09

F	25000	Transportation Cost	3885.7
H	75000		

Figure 4.11 Solutions of Transportation Model Part I

Transportation cost: 3885.7 Baht

Opened farms: F2 (Chonburi) 25000 units

F5 (Nakhon Si Thammarat) 25000 units

F7 (Phuket) 20000 units

(Note: These quantities are going to be demanded for the Transportation model Part II)

4.2.2 Formulation of Transportation Model Part II

Assume that there are 4 hatcheries supplying a small size abalone; and each supply can offer 75,000 units. From transportation models part I, total demand from customers is 70,000 units; demands from customers F1 through F13 are 0, 25000, 0, 0, 25000, 0, 20000, 0, 0, 0, 0, 0, and 0 units, respectively; thus, one hatchery should be opened.

The model's formula is following:

Objective:

$$\text{Min. } [.01X_{H1,F1} + .41X_{H1,F2} + \ldots\ldots\ldots X_{H4,F13}]$$

Where $X_{H1,F1}$, $X_{H1,F2}$,…….$X_{H4,F13}$ are decision variables;

H1, H2, ……, H4 are hatcheries

F1, F2, ……, F13 are farms

Subject to constraints:

Supply side: if each supply is 75,000 units right hand side (RHS) will be 75,000.

$$X_{H1,F1}+X_{H1,F2}+\ldots.+X_{H1,F13} \leq 75{,}000$$

$$X_{H2,F1}+X_{H2,F2}+\ldots.+X_{H2,F13} \leq 75{,}000$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$X_{H4,F1}+X_{H4,F2}+\ldots.+X_{H4,F13} \leq 75{,}000$$

Demand side: demands are 0, 25000, 0, 0, 25000, 0, 20000, 0, 0, 0, 0, 0, and 0 units; then, RHS is equal to these demands.

$$X_{H1,\,F1}+X_{H2,\,F1}+\ldots+X_{H4,\,F1} \geq 0$$

$$X_{H1,\,F2}+X_{H2,\,F2}+\ldots+X_{H4,\,F2} \geq 25{,}000$$

$$X_{H1,\,F3}+X_{H2,\,F3}+\ldots+X_{H4,F3} \geq 0$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$X_{H1,\,F13}+X_{H2,\,F13}+\ldots+X_{H4,F13} \geq 0$$

To solve this problem with Excel program, input data are as follows:

1. We transform these formulas into Excel program as shown in Figure 4.12.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total			Capacity	y/n
H1														0	<=	0	75000	
H2														0	<=	0	75000	
H3														0	<=	0	75000	
H4														0	<=	0	75000	
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	=	70000		0
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
	0	25000	0	0	25000	0	20000	0	0	0	0	0	0					1
Capacity	0	25000	0	0	25000	0	20000	0	0	0	0	0	0					
y/n	0	1	0	0	1	0	1	0	0	0	0	0	0	3				

Changing here

Capacity		Site		
H	75000	0.9333	Transportation cost	0
F	25000	2.8		

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
H1	0.01	0.00	0.06	0.10	0.09	0.09	0.10	0.04	0.06	0.02	0.12	0.08	0.10
H2	0.12	0.10	0.04	0.00	0.02	0.02	0.02	0.06	0.03	0.11	0.03	0.02	0.01
H3	0.06	0.04	0.02	0.06	0.05	0.06	0.06	0.00	0.03	0.05	0.08	0.04	0.06
H4	0.13	0.12	0.06	0.03	0.02	0.04	0.05	0.08	0.06	0.13	0.00	0.04	0.01

Figure 4.12 Transportation Model using Excel Program- Hatchery to Farm

2. Using Solver to solve the problem, add Solver into Excel program, and click Solver in order to input parameters into Solver parameters box.

3. In Solver Parameters box as shown in Figure 4.13, we input parameters as follow:

   Set Target Cell: G17

Equal To: min.

By Changing Cells: $B$2:$N$5, S:$S$14

Subject to the Constraints:

$B$2:$N$6 >=$B$8:$N$8

$O$2:$O$5 <= $O$2:$O$5

$S$6 <= $S$8

$S$2:$S$5 = binary

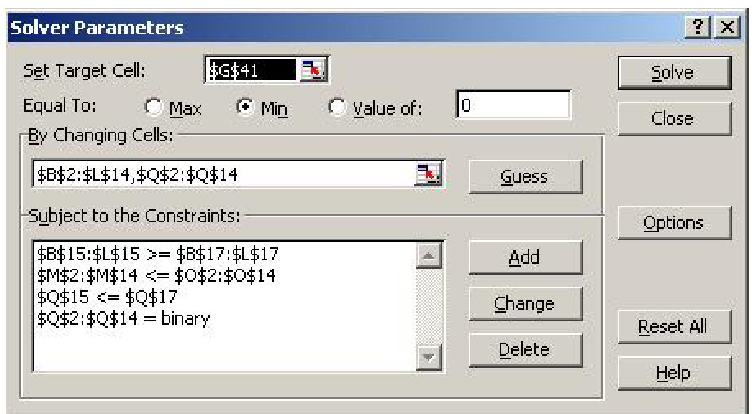


Figure 4.13 Solver Parameters Box – Hatchery to Farm

4. Click Solve button; it goes to Solver Results. Solver gives the solution that satisfies all constraints and optimality conditions. Click OK.
5. The solution as shown in Figure 4.14 is as follow:

Transportation cost: 3388 Baht

Opened farms: H2 (Krabi), 70,000 units

Then, we find total transportation cost by sum of the two transportation models.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total			Capacity	y/n
H1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	-1.7E-07	75000	-0
H2	0	25000	0	0	25000	0	20000	0	0	0	0	0	0	70000	<=	75000	75000	1
H3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	75000	0
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	75000	0
Total	0	25000	0	0	25000	0	20000	0	0	0	0	0	0	70000	=	70000		1
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
	0	25000	0	0	25000	0	20000	0	0	0	0	0	0					1
Capacity	0	25000	0	0	25000	0	20000	0	0	0	0	0	0					
y/n	0	1	0	0	1	0	1	0	0	0	0	0	0	3				

Changing here

Capacity		Site		
H	75000	0.9333	Transportation cost	3388.3
F	25000	2.8		

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
H1	0.01	0.00	0.06	0.10	0.09	0.09	0.10	0.04	0.06	0.02	0.12	0.08	0.10
H2	0.12	0.10	0.04	0.00	0.02	0.02	0.02	0.06	0.03	0.11	0.03	0.02	0.01
H3	0.06	0.04	0.02	0.06	0.05	0.06	0.06	0.00	0.03	0.05	0.08	0.04	0.06
H4	0.13	0.12	0.06	0.03	0.02	0.04	0.05	0.08	0.06	0.13	0.00	0.04	0.01

Figure 4.14 Solution of Transportation Model Part II

4.3 Excel Solution

The solutions from two transportation models focus on costs and activities in network system. Transportation model part I finds minimum cost of transportation from farms to customers, and transportation model part II finds minimum cost of transportation from hatchery to farms.

4.3.1 Cost:

When demand is 70,000 units, the total cost including total fixed cost, total variable cost and total transportation cost is B/.2.7 million. The total fixed cost including fixed cost of three farms and one hatchery is B/.582393; the total variable cost including variable cost of three farms and one hatchery is B/. 2,149,000. Finally, the total transportation cost including transportation of hatcheries to farms and of farms to customers is B/. 7,274. Details of solution is shown in Figure 4.15.

Cost	
Total Fixed Cost	B/. 582,393
Total Variable Cost	B/. 2,149,000
Total Transportation Cost	B/. 7,274
Total Cost	**B/. 2,738,667**
Demand	70000
H-Supply	70000
F-Supply	70000
Fixed Cost	
Hatchery	B/. 36,243
Farming	B/. 182,050
Variable Cost	
Hatchery	B/. 1.08
Farming	B/. 29.62
Transportation Cost	
Farm to Customer	3885.7
Hatchery to Farm	3388.3
Location' site	
No. of Hatchery	1
No. of Farming	3

Figure 4.15 Cost of Abalone Farm at Demand of 70,000 Units per Month

4.3.2 Activities:

From transportation model part I in Figure 4.16, hatchery H2 is selected with supply 70,000 units per month; the number of 25,000, 25,000, and 20,000 units per month are shipped to farms F2, F5 and F7, respectively.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total			Capacity	y/n
H1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	-1.7E-07	75000	-0
H2	0	25000	0	0	25000	0	20000	0	0	0	0	0	0	70000	<=	75000	75000	1
H3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	75000	0
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	75000	0
Total	0	25000	0	0	25000	0	20000	0	0	0	0	0	0	70000	=	70000		1
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
	0	25000	0	0	25000	0	20000	0	0	0	0	0	0					1
Capacity	0	25000	0	0	25000	0	20000	0	0	0	0	0	0					
y/n	0	1	0	0	1	0	1	0	0	0	0	0	0	3				

Figure 4.16 Small Demand Optimal Solutions – Hatcheries to Farms

From transportation model part II in Figure 4.17, farms F2, F5 and F7 are selected to ship to customers. F2 is going to ship to C1 with requirement of 25,000 units per month; F7 is going to ship to C8 with the requirement of 15,000 units per month; F5 is going to ship to C10 with the requirement of 15,000 units per month; and, F5 and F7 are going to ship to C11 with the requirement of 15,000 units per month, meanwhile, F5 will ship 5,000 units and F7 will ship 5,000 units.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total			Capacity	y/n
F1	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.9E-12	25000	0
F2	25000	0	0	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1
F3	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F4	0	0	0	0	0	0	0	0	0	0	0	0	<=	-5E-28	25000	-0
F5	0	0	0	0	0	0	0	0	0	15000	10000	25000	<=	25000	25000	1
F6	0	0	0	0	0	0	0	0	0	0	0	0	<=	-8E-13	25000	-0
F7	0	0	0	0	0	0	0	15000	0	0	5000	20000	<=	25000	25000	1
F8	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F9	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F10	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F11	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F12	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F13	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
Total	25000	0	0	0	0	0	0	15000	0	15000	15000	70000				3
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
Demand	25000	0	0	0	0	0	0	15000		15000	15000	70000				3

Figure 4.17 Small Demand Optimal Solutions ─ Farms to Customers

The supply chain system for these models is shown in Figure 4.18.

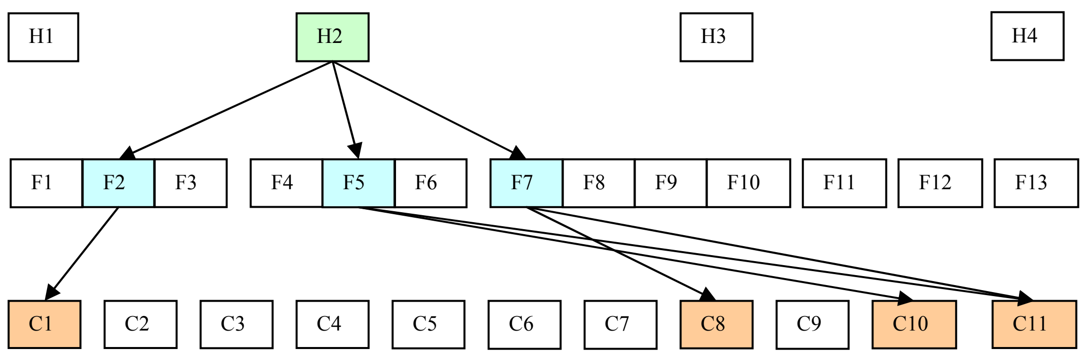


Figure 4.18 Small Demand Optimal Shipments from Hatchery to Farms to Customers

4.4 Various Demands

Various demands have been set up and classified into three categories, i.e., small, medium, and large demands. As shown in Table 4.1, small demand is 70,000 units per month. Because the maximum capacity of a farm is 25,000 units per month, the minimum number of farms is three. A capacity of a hatchery is 75,000 units per month, so one hatchery is required.

Table 4.1 Customer Demands

Units (in thousand)

Demand	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	Total Demands	No. of Farm	No. of Hatchery
Small	25							15		15	15	70	3	1
Medium	30	5		5	5	5		20	5	20	20	115	5	2
	35	10	5	15	10	10	5	20	10	20	20	160	7	3
Large	40	15	10	15	20	15	10	20	20	20	20	205	9	3
	45	20	25	20	20	15	20	20	20	20	20	245	10	4

Hatchery's capacity 75 Farm's capacity 25

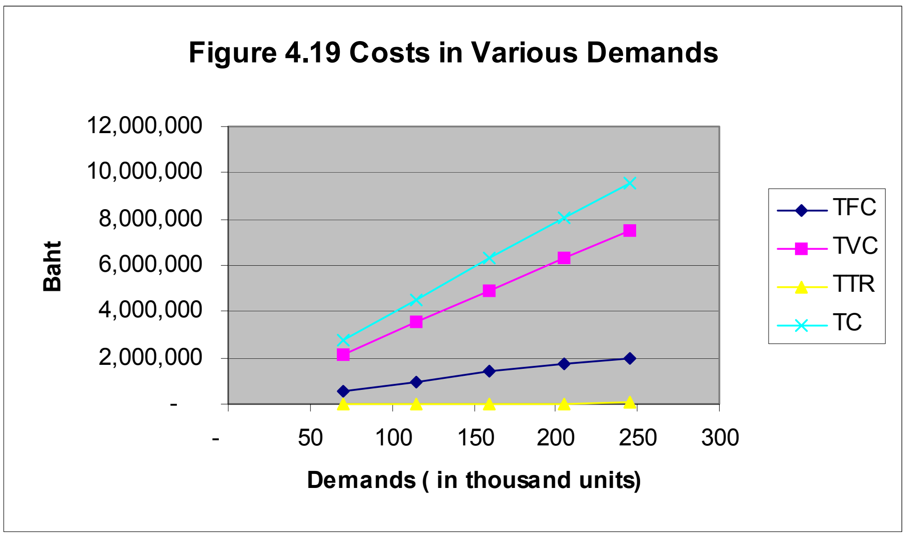
In medium demand, two scenarios are set up, 115,000 and 160,000 units per month. When demand is 115,000 units per month, five farms and two hatcheries will open. When demand is 160,000 units per month, seven farms and three hatcheries will open.

In large demand, two scenarios are set up, 205,000 and 245,000 units per month. When demand is 205,000 units per month, nine farms and three hatcheries will open. When demand is 245,000 units per month, ten farms and four hatcheries will open.

4.5 Solutions (Details of calculation see appendix C)

4.5.1 Cost: The summary solutions of various demands are shown in Table 4.2. Costs are increased when demands and number of farms and hatcheries are increased as shown in Figure 4.19.

Table 4.2 Costs in Various Demands					
Type	Demand (Thousand)	TFC	TVC	TTR	TC
Small	70	582,393	2,149,000	7,274	2,738,667
Medium	115	982,736	3,530,500	10,748	4,523,984
Medium	160	1,383,079	4,912,000	20,351	6,315,430
Large	205	1,747,179	6,293,500	34,094	8,074,773
Large	245	1,965,472	7,521,500	50,605	9,537,577
Note:					
TFC: Total Fixed Cost			TTR: Total Transportation Cost		
TVC: Total Variable Cost			TC: Total Cost		



4.5.2 Activities: The summary solution of three categories, small demand, medium demand and large demand. First, with small demand, the solution is shown in Figure 4.20 and 4.21. A hatchery, H2, will ship to farms F2, F5, and F7 with the quantities 25,000, 25,000, and 20,000 units respectively.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total
H1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2	0	25000	0	0	25000	0	20000	0	0	0	0	0	0	70000
H3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	25000	0	0	25000	0	20000	0	0	0	0	0	0	70000

Figure 4.20 Small Demand Optimal Solutions – Hatcheries to Farms

Farm F2 will ship to a customer C1, 25000 units. Farm F5 will ship to customers, C10 and C11 with 15,000 and 10,000 units respectively. Farm F7 will ship to customers, C8 and C11 with 15,000 and 5,000 units respectively.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total
F1	0	0	0	0	0	0	0	0	0	0	0	0
F2	25000	0	0	0	0	0	0	0	0	0	0	25000
F3	0	0	0	0	0	0	0	0	0	0	0	0
F4	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0	0	0	0	0	0	0	15000	10000	25000
F6	0	0	0	0	0	0	0	0	0	0	0	0
F7	0	0	0	0	0	0	0	15000	0	0	5000	20000
F8	0	0	0	0	0	0	0	0	0	0	0	0
F9	0	0	0	0	0	0	0	0	0	0	0	0
F10	0	0	0	0	0	0	0	0	0	0	0	0
F11	0	0	0	0	0	0	0	0	0	0	0	0
F12	0	0	0	0	0	0	0	0	0	0	0	0
F13	0	0	0	0	0	0	0	0	0	0	0	0
Total	25000	0	0	0	0	0	0	15000	0	15000	15000	70000

Figure 4.21 Small Demand Optimal Solutions – Farms to Customers

Second, with medium demand, there are two demands, 115,000 and 160,000 units per month. When demand is 115000 units per month, the solution is shown in Figure 4.22 and Figure 4.23.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total
H1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2	0	0	0	25000	25000	0	0	0	0	0	0	0	15000	65000
H3	0	0	0	0	0	0	0	25000	25000	0	0	0	0	50000
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total				0	25000			5000	25000					000

Figure 4.22 Medium Demand Optimal Solutions – Hatcheries to Farms (115000)

Hatchery H2 will ship to farms F4, F5 and F13, 25000, 25000, and 15000 units per month respectively. H3 will ship to F8 and F9, 25000 units per month for each farm.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total
F1	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	0	0	0	0	0	0	0	0	0	0	0
F3	0	0	0	0	0	0	0	0	0	0	0	0
F4	0	0	0	0	0	0	0	0	0	5000	20000	25000
F5	0	0	0	0	0	0	0	5000	5000	15000	0	25000
F6	0	0	0	0	0	0	0	0	0	0	0	0
F7	0	0	0	0	0	0	0	0	0	0	0	0
F8	0	0	0	0	5000	5000	0	15000	0	0	0	25000
F9	15000	5000	0	5000	0	0	0	0	0	0	0	25000
F10	0	0	0	0	0	0	0	0	0	0	0	0
F11	0	0	0	0	0	0	0	0	0	0	0	0
F12	0	0	0	0	0	0	0	0	0	0	0	0
F13	15000	0	0	0	0	0	0	0	0	0	0	15000
Total	30000	5000	0	5000	5000	5000	0	20000	5000	20000	20000	115000

Figure 4.23 Medium Demand Optimal Solutions – Farms to Customers (115000)

Farm F4 will ship to customers C10 and C11, 5,000 and 20000 units per month respectively. Farm F5 will ship to customers C8, C9 and C10, 5000, 5000, and 15000 units per month respectively. Farm F9 will ship to customers C1, C2 and C4, 15000, 5000, and 5000 units per month respectively. Finally, farm F13 will ship to customer C1, 15000 units per month. Network system of this demand is shown in Figure 4.24.

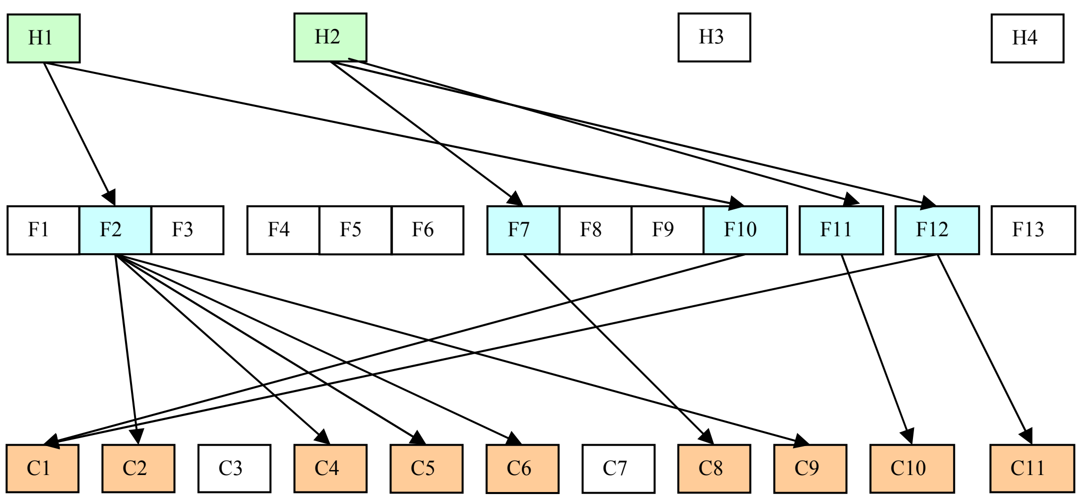


Figure 4.24 Medium Demand Optimal Shipments - Hatchery to Farms to Customers

When demand is 160,000 units per month, the solution is shown in Figure 4.25 and Figure 4.26.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total
H1	25000	25000	0	0	0	0	0	0	0	25000	0	0	0	75000
H2	0	0	0	0	0	0	20000	0	0	0	20000	25000	0	65000
H3	0	0	0	0	0	0	0	20000	0	0	0	0	0	20000
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	25000	25000	0	0	0	0	20000	20000	0	25000	20000	25000	0	160000

Figure 4.25 Medium Demand Optimal Solutions – Hatcheries to Farms (160000)

Hatchery H1 will ship to farms F1, F2 and F10, 25000, 25000, and 25000 units per month respectively. H2 will ship to F7, F11 and F12, 20000, 20000, and 25000 units per month. Finally, H3 will ship to F8, 20000 units per month.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total
F1	0	0	0	15000	10000	0	0	0	0	0	0	25000
F2	0	10000	5000	0	0	10000	0	0	0	0	0	25000
F3	0	0	0	0	0	0	0	0	0	0	0	
F4	0	0	0	0	0	0	0	0	0	0	0	
F5	0	0	0	0	0	0	0	0	0	0	0	
F6	0	0	0	0	0	0	0	0	0	0	0	
F7	0	0	0	0	0	0	0	20000	0	0	0	
F8	20000	0	0	0	0	0	0	0	0	0	0	
F9	0	0	0	0	0	0	0	0	0	0	0	
F10	15000	0	0	0	0	0	0	0	10000	0	0	25000
F11	0	0	0	0	0	0	0	0	0	20000	0	
F12	0	0	0	0	0	0	5000	0	0	0	20000	25000
F13	0	0	0	0	0	0	0	0	0	0	0	
Total	35000	10000	5000	15000	10000	10000	5000	20000	10000	20000	20000	160000

Figure 4.26 Medium Demand Optimal Solutions – Farms to Customers (160000)

Farm F1 will ship to customers C4 and C5, 15000 and 10000 units per month respectively. Farm F2 will ship to customers C2, C3 and C6, 10000, 5000, and 10000 units per month respectively. Farm F7 will ship to customers C8, 20000 units per month. Farm F8 will ship to C1, 20000 units per month. Farm F10 will ship to C1 and C9, 15000 and 10000 units per month respectively. Farm F11 will ship to C10, 20000 units per month. Finally, farm F12 will ship to customer C7 and C11, 5000 and 20000 units per month respectively. Network system of this demand is shown in Figure 4.27.

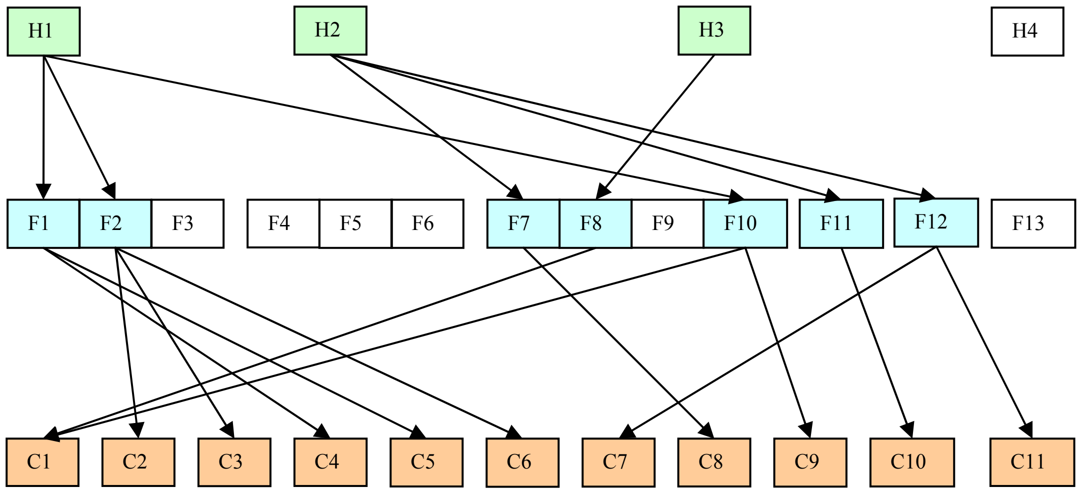


Figure 4.27 Medium Demand Optimal Shipments - Hatchery to Farms to Customers (160,000)

Third, with large demand, there are two demands, 205,000 and 245,000 units per month. When demand is 205,000 units per month, the solution is shown in Figure 4.28 and Figure 4.29.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total
H1	25000	25000	0	0	0	0	0	0	0	25000	0	0	0	75000
H2	0	0	0	0	25000	0	20000	0	0	0	0	25000	0	70000
H3	0	0	25000	0	0	0	0	25000	10000	0	0	0	0	60000
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	25000	25000	25000	0	25000	0	20000	25000	10000	25000	0	25000	0	205000

Figure 4.28 Large Demand Optimal Solutions – Hatcheries to Farms (205000)

Hatchery H1 will ship to farms F1, F2 and F10, 25000, 25000, and 25000 units per month respectively. H2 will ship to F5, F7 and F12, 25000, 20000, and 25000 units per month. Finally, H3 will ship to F3, F8 and F9, 25000, 25000, and 10000 units per month.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total
F1	0	0	0	5000	20000	0	0	0	0	0	0	25000
F2	0	0	10000	0	0	15000	0	0	0	0	0	25000
F3	10000	15000	0	0	0	0	0	0	0	0	0	25000
F4	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0	0	0	0	5000	0	0	20000	0	25000
F6	0	0	0	0	0	0	0	0	0	0	0	0
F7	0	0	0	0	0	0	0	20000	0	0	0	20000
F8	25000	0	0	0	0	0	0	0	0	0	0	25000
F9	0	0	0	10000	0	0	0	0	0	0	0	10000
F10	5000	0	0	0	0	0	0	0	20000	0	0	25000
F11	0	0	0	0	0	0	0	0	0	0	0	0
F12	0	0	0	0	0	0	5000	0	0	0	20000	25000
F13	0	0	0	0	0	0	0	0	0	0	0	0
Total	40000	15000	10000	15000	20000	15000	10000	20000	20000	20000	20000	205000

Figure 4.29 Large Demand Optimal Solutions – Farms to Customers (205,000)

Farm F1 will ship to customers C4 and C5, 5000 and 20000 units per month respectively. Farm F2 will ship to customers C3 and C7, 10000, and 15000 units per month respectively. Farm F3 will ship to customer C1 and C2, 10000 and 15000 units per month respectively. Farm F5 will ship to customer C7 and C10, 5000 and 20000 units per month respectively. Farm F7 will ship to customers C8, 20000 units per month. Farm F8 will ship to C1, 25000 units per month. Farm F9 will ship to customer C4, 10000 units per month. Farm F10 will ship to C1 and C9, 5000 and 20000 units per month respectively. Finally, farm F12 will ship to customer C7 and C11, 5000 and 20000 units per month

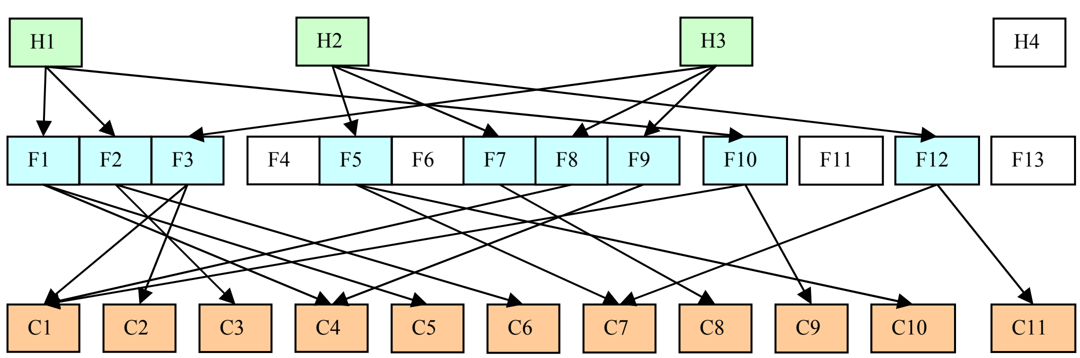


Figure 4.30 Large Demand Optimal Shipments - Hatchery to Farms to Customer (205,000)

respectively. Network system of this demand is shown in Figure 4.30.

When demand is 245,000 units per month, the solution is shown in Figure 4.31 and Figure 4.32.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total
H1	25000	25000	0	0	0	0	0	0	0	25000	0	0	0	75000
H2	0	0	0	0	0	0	20000	0	0	0	0	25000	25000	70000
H3	0	0	25000	0	0	0	0	25000	25000	0	0	0	0	75000
H4	0	0	0	0	25000	0	0	0	0	0	0	0	0	25000
Total	25000	25000	25000	0	25000	0	20000	25000	25000	25000	0	25000	25000	245000

Figure 4.31 Large Demand Optimal Solutions – Hatcheries to Farms (245000)

Hatchery H1 will ship to farms F1, F2 and F10, 25000, 25000, and 25000 units per month respectively. H2 will ship to F7, F12 and F13, 20000, 25000, and 25000 units per month. H3 will ship to F3, F8 and F9, 25000, 25000, and 25000 units per month. Finally, H4 will ship to F5 25000 units per month.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total
F1	0	0	0	15000	10000	0	0	0	0	0	0	25000
F2	0	5000	0	5000	0	15000	0	0	0	0	0	25000
F3	10000	0	15000	0	0	0	0	0	0	0	0	25000
F4	0	0	0	0	0	0	0	0	0	0	0	
F5	0	0	0	0	0	0	20000	0	0	5000	0	25000
F6	0	0	0	0	0	0	0	0	0	0	0	
F7	0	0	0	0	0	0	0	20000	0	0	0	
F8	25000	0	0	0	0	0	0	0	0	0	0	25000
F9	0	15000	10000	0	0	0	0	0	0	0	0	25000
F10	5000	0	0	0	0	0	0	0	20000	0	0	25000
F11	0	0	0	0	0	0	0	0	0	0	0	
F12	5000	0	0	0	0	0	0	0	0	0	20000	25000
F13	0	0	0	0	10000	0	0	0	0	15000	0	25000
Total	45000	20000	25000	20000	20000	15000	20000	20000	20000	20000	20000	245000

Figure 4.32 Large Demand Optimal Solutions – Farms to Customers (245000)

Farm F1 will ship to customers C4 and C5, 15,000 and 10,000 units per month respectively. Farm F2 will ship to customers C2, C4 and C6, 5,000, 5,000and 15,000 units per month respectively. Farm F3 will ship to customer C1 and C3, 10,000 and 15,000 units per month respectively. Farm F5 will ship to customer C7 and C10, 20,000 and 5,000 units per month respectively. Farm F7 will ship to customers C8, 20,000 units per month. Farm F8 will ship to C1, 25,000 units per month. Farm F9 will ship to customer C2 and C3, 15,000 and 10,000 units per month. Farm F10 will ship to C1 and C9, 5,000 and 20,000 units per month respectively. Farm F12 will ship to customer C1 and C11, 5,000 and 20,000 units per month respectively. Finally, farm F13 will ship to customer C5 and C10, 10,000 and 15,000 units per month respectively. Network system of this demand is shown in Figure 4.33.

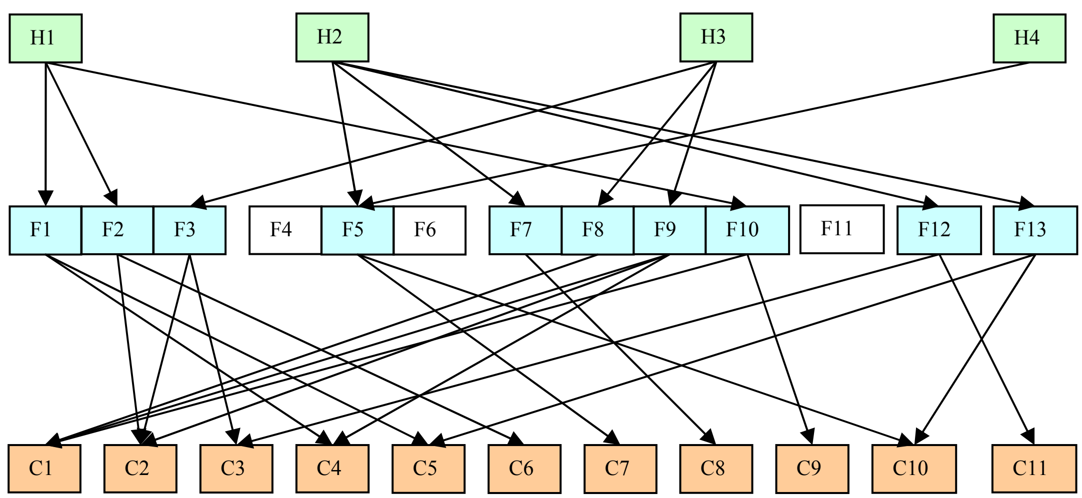


Figure 4.33 Large Demand Optimal Shipments - Hatchery to Farms to Customers (245,000)

4.5.3 Summary

The solution of the transportation models with various demands are shown in Table 4.3. When demands change, design supply chain planning process i.e. number of farms and hatcheries needed, growing location, and total cost, needs to be reexamined. For example, in small demand, when we know that one hatchery and three farms will be opened, this simulation model will give the solution as to which hatcheries or farms will be opened, and what is the cost of the system. In this case, hatchery H2 will be opened, and it will supply to farms F2, F5 and F7 to grow; these farms will supply their product to potential customers; the total cost will be B/ 2,738,667 per month.

When we have large demand, the number of hatcheries and farms will change, and, at the same time, the total costs will change as well. For example, when demand goes to 245,000 units per month, all hatcheries in this network system will open, and ten farms will be opened to supply eleven customers. The total cost will go up to B/.9.5 million per month. One cannot keep the optimal solution as costs increase without closing farms, which is not practical. Therefore, one will have to use sub-optimal solutions for some demands.

Table 4.3 Summary of solutions in various demands

Type	Demand (Thousand)	Opened Hatcheries		Opened Farms		Customers		Total Cost
Small	70	H2	1	F2,F5,F7	3	C1,C8,C10,C11	4	2,738,667
Medium	115	H1, H2	2	F2, F7, F10, F11, F12	5	C1, C2, C4, C5, C6, C8, C9, C10, C11	9	4,523,984
Medium	160	H1, H2, H3	3	F1, F2, F7, F8, F10, F11, F12	7	ALL	11	6,315,430
Large	205	H1, H2, H3	3	All except F4, F6, F11, F13	9	ALL	11	8,074,773
Large	245	ALL	4	All except F4, F6, F11	10	ALL	11	9,537,577

Chapter 5

Conclusion

Three species of abalone have been found in the Golf of Thai and Andaman Sea, *Holiotis asinina*, *Holiotis ovina*, and *Holiotis varia*. *Holiotis asinina* is a fast growing abalone, so this species is selected to study in commercial scale. The studies are not only how to grow in hatcheries but also how to grow in order to find the optimal value in the economic scale before launching into the market. Then, the fixed cost and variable cost were studied.

Thus, products are hatchery size abalone and farm size abalone. In producing abalone products, hatchery size abalone is focused on farms that are the customers, and farm size abalone is focused on consumers such as the food centers, restaurants, and supermarkets. Then, supply chain management is the strategic planning to use in this study in order to eliminate wastes of the system.

The program is used as a tool to design the supply chain system. In the abalone farm project, the model is used to design the distribution system to provide the minimum cost of transportation, the quantity into or from each farm where abalone is to be shipped, and which hatchery will supply each farm.

Design supply chain system is important for this abalone project because it will be a prototype for other projects, which have the same type of distribution system. It can apply to agricultural products and others in order to minimize the cost. For example, it applies to the farms of mango, durian, and shrimp, etc. This LP model shows possible scenarios when parameters are changed, and the results give nearly optimal solutions.

The advantage of supply chain management is that it is a tool for managers so that they can manage the distribution system efficiently and effectively in order to compete with low costs in the world market.

In this case, Solver could only do small problems because the number of parameters is limited to 200 decision variables (Frontline Systems, 2003). For example, when working on this program with a small number of parameters such as two hatcheries, three farms and three customers, Solver could run properly because there were only 20 parameters. On the other hand, when we changed the problem to four hatcheries, thirteen farms, and eleven customers, there were 212 parameters, too many parameters to solve with Solver. Thus, the transportation model is split into two parts so that the problems can be solved.

However, to solve large problems, there are other versions of Solver programs such as Premium Solver, Large-Scale Linear Programming Solver, and XPRESS Solver Engine (Frontline Systems, 2003).

References:

Auram Siam. (2003). Driving Distance of Cities. Retrieved on April 4, 2003 from http://www.panteethai.com/1024/distance_city.asp.

Bogart Designs. (2003). Facts About Abalone, FISHTECH Question and Answer FISHTECH, INC. Retrieved on March 23, 2003 from http://www.fishtech.com/facts.html.

Council of Logistics Management (CLM). (2003). "Definition of Logistics". Retrieved on March 25, 2003 from http://www.clm1.org.

Department of Fishery (2002). Capital cost of Abalone Production, Meeting on Network of the Research and Development on Plant and Animal Aquaculture Industry, Research Progression Bring Thai Farmers to International, Chulalongkorn University, July19-20, 2002.

Frontline Systems Inc. (2003). Solver Technology – Linear Programming and Quadratic Programming, Retrieved on April 19, 2003 from http://www.solver.com/technology2.htm

Heizer, J., and Render B.(1999). Operations Management, Fifth Edition, Upper Saddle River, New Jersey: Prentice Hall.

Institute of Intellectual Property of Chulalongkorn University and C&C International Venture Co., Ltd. (2001). Final Report on Study of Reality of Transportation Cost on Land, Water and Train, Ministry of Transport of Thailand, 2001.

Jarayabhand, P.(2001). Development on Commercial Production of Cocktail Size Abalone, *Haliotis aninine* by Land Based System. Aquatic Resources Research

Institute Chulalongkorn University, June 2001, p. 14-18.

Jarayabhand, P.(2002), Development of Commercial Production of Cocktail Size Abalone, by Land Based System, Meeting on Network of the Research and Development on Aquatic Plant and Animal Industry, Research Progression Bring Thai Farmers to International, Chulalongkorn University, July19-20, 2002.

Moore, H. Jeffrey, and Weatherford, R. Larry (2001). Decision Modeling with Microsoft® Excel, Sixth Edition, Upper Saddle River, New Jersey: Prentice Hall.

Office of Technology Promotion and Transfer (OTPT) (2003). Summary Report on the Performance of the Supporting the Invention Project for Rural Development. [Online], Retrieved on March 20, 2003, from www.ttc.moste.go.th.

Sahawacharin, Songchai and Pumthong, Thanas (2003). Development on Commercial Producing of Thai Abalone, *Haliotis asinina* and *Haliotis ovina* species. The Thailand Research Fund. Retrieved on March 23, 2003 from http://pioneer.netserv.chula.ac.th/~jpaderms/act.htm.

Shapiro, F. Jeremy (2001). Modeling the Supply Chain. Pacific Grove, CA: Brooks/Cole-Thomson Learning.

Simchi-Levi, D., and Kaminsky, P, Simchi-Levi, E. (2000). Designing and Management the Supply Chain: Concepts, Strategies, and Case studies. Boston: Irwin/McGraw-Hill.

Tiravanit, Suppaluk (2003). Realized Heritability Estimation on Growth Rate of Donkey's Ear Abalone. Faculty of Marine Science, Chulalongkorn University, March 23, 2003.

Tuntraporn, Viroj (2003). Research for Recovery Country from Crisis. Retrieved on March 25, 2003 from www.moste.go.th/s&tmanpower/Misc-page/Misc-page.htm.

Appendix A

Abalone Hatchery

A model of the Abalone Farm was designed by Department of Fishery[1] (2003). Details were following:

Hatchery						
					Estimate Cost 10 years	
Fix cost	**cost**	**year**	**i**	**A (Baht/mo)**		
1. Building, utility	40000	5	0.06	773		
1.1 Building	51000	5		986		
1.2 Tank(5 ton) 6 unit	14000	5		271		
1.3 Tank(2 ton) 2 unit	4800	5		93		
1.4 Alge tank 2 unit	40000	10		444		
1.5 Air Pump 2 unit	60000	10		666		
1.6 Water Pump 2 un	250000	5		4,833		
1.7 Sand Filter	50000	5		967		
1.8 Filter (1 micron)	3000	10		33		
2. Dark- Lab	30000	10		333		
3. Nursery Tank(1 ton	104920	10		1,165		
4. Room for food prep	100000	10		1,110		
5. Pond	2000	5		39		
6. Owen	10000	10		111		
7. Glider	5000	5		97		
8. Plastic Sheets	8300	5		160		
Total fix cost	**773020**	10	0.06	**12,081**	B/. 1,088,177	
Variable cost						
Abalone	10000	3	0.06	304		
Food 1stage				3,000		
manager				8,000		
labor 2 persons				9,000		
Utilities expense				5,000		
Food 2stage				264		
Other				1,500		
Total VC		**10**	**0.06**	**27,068**	B/. 2,438,128	
Out put						
Duration	5 m					
Avrage output	25000	seed/month			3000000	
Total cost	1.57	Baht			BHD 1.18	
Fixed cost per seed	0.48	Baht			BHD 0.36	
Variable cost per see	1.08	Baht			BHD 0.81	
If P	10	Baht				
BEP	3	months				

[1] Department of Fishery, Capital cost of Abalone Production, Meeting on Network of the Research and Development on Plant and Animal Aquaculture Industry, Research progression bring Thai Farmers to International, Chulalongkorn University, July19-20, 2002.

Total fixed cost was B/. 1,088,177. It could be used for a10 year period. Assume that the interest was 6 % per year. Annual worth payment was B/.12,081 per month. The variable cost was B/.27, 068 per month.

Capacity of this model was 25000 units per month.

Appendix B

Abalone Farm

A model of the Abalone Farm was designed by Jarayabhand (2002)[2]

Total fixed cost was B/. 1,639,825. It could be used for a10 year period. Assume that the interest was 6 % per year. Annual worth payment was B/.18,205 per month. The variable cost was B/.74, 049 per month.

Capacity of this model was 2500 units per month. Details are following:

Farming					
Fixed Cost		year	i	A (Baht/mo)	
Building & Land Improvement	1,000,000	10	0.06	11,102	
Tank	100,000	5		1,933	
Facilities	50,000	5		967	
Duct & Valve	100,000	10		1,110	
Water Pump	100,000	5		1,933	
Air Pump	60,000	5		1,160	
Total Fixed Cost	1,410,000	10	0.06	18,205	B/. 1,639,825
Variable Cost					
total expend	1,670,762	2		74,049	
		10	0.06		B/. 6,669,866.39
Out put					
Duration	24	months			
Average out put	2500	seed/month			300000
Total Cost/seed	B/. 36.90				B/. 27.70
Fixed Cost/seed	B/. 7.28				B/. 5.47
Variable Cost/seed	B/. 29.62				B/. 22.23
P	B/. 100				
BEP	8	months			
	20034	seeds			

[2] Jarayabhand, P.(2002), Development of Commercial Production of Cocktail Size Abalone, by Land Based System, Meeting on Network of the Research and Development on Aquatic Plant and Animal Industry, Research progression bring Thai Farmers to International, Chulalongkorn University, July19-20, 2002.

Appendix C

Simulation model's solution

Solutions of Simulation model with various demands are shown in Table 4.1. Demands are classified into three categories, small, medium, and large demands. Small demand is 70,000 units per month. Medium demands are 115,000 and 160,000 units per month. Large demands are 205,000 and 245,000 units per month.

Table 4.1 Customer Demands

Units (in thousand)

Demand	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	Total Demands	No. of Farm	No. of Hatchery
Small	25							15		15	15	70	3	1
Medium	30	5		5	5	5		20	5	20	20	115	5	2
	35	10	5	15	10	10	5	20	10	20	20	160	7	3
Large	40	15	10	15	20	15	10	20	20	20	20	205	9	3
	45	20	25	20	20	15	20	20	20	20	20	245	10	4
Hatchery's capacity			75		Farm's capacity				25					

Small Demand: 70,000 units per month.

Find minimum transportation cost from farms to customers.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total			Capacity	y/n		
F1	0	0	0	0	0	0	0	0	0	0	0	0	<=	6E-12	25000	0	<=	1
F2	25000	0	0	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1	<=	1
F3	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F4	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F5	0	0	0	0	0	0	0	0	0	15000	10000	25000	<=	25000	25000	1	<=	1
F6	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F7	0	0	0	0	0	0	0	15000	0	0	5000	20000	<=	25000	25000	1	<=	1
F8	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F9	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F10	0	0	0	0	0	0	0	0	0	0	0	0	<=	-2E-13	25000	-0	<=	1
F11	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F12	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F13	0	0	0	0	0	0	0	0	0	0	0	0	<=	9.2E-07	25000	0	<=	1
Total	25000	0	0	0	0	0	0	15000	0	15000	15000	70000				3		
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=		
Demand	25000	0	0	0	0	0	0	15000		15000	15000	70000				3		

Cost of transportation from farming to customers (Baht/unit)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
F1	0.10	0.41	0.45	0.28	0.13	0.21	0.45	0.48	0.13	0.52	0.39
F2	0.07	0.34	0.38	0.23	0.11	0.13	0.38	0.41	0.08	0.45	0.32
F3	0.20	0.51	0.55	0.40	0.32	0.31	0.13	0.18	0.25	0.22	0.08
F4	0.36	0.66	0.70	0.55	0.47	0.46	0.09	0.07	0.40	0.13	0.09
F5	0.34	0.65	0.68	0.54	0.45	0.45	0.00	0.14	0.39	0.07	0.05
F6	0.34	0.65	0.69	0.54	0.46	0.45	0.10	0.08	0.39	0.18	0.08
F7	0.38	0.68	0.72	0.57	0.49	0.48	0.14	0.00	0.42	0.22	0.12
F8	0.11	0.43	0.47	0.32	0.24	0.23	0.22	0.25	0.16	0.29	0.15
F9	0.25	0.55	0.59	0.44	0.36	0.35	0.14	0.12	0.29	0.23	0.09
F10	0.07	0.38	0.42	0.27	0.14	0.18	0.42	0.45	0.11	0.49	0.36
F11	0.43	0.73	0.77	0.62	0.54	0.53	0.09	0.20	0.47	0.05	0.15
F12	0.28	0.59	0.62	0.48	0.39	0.39	0.05	0.12	0.33	0.12	0.00
F13	0.36	0.67	0.70	0.56	0.36	0.47	0.05	0.13	0.41	0.07	0.09

F	25000	Transportation Cost	3885.7
H	75000		

minimize transportation cost,G41.
condition y/n <13
Solution is

	C	F	Tr-Cost
1	25000	0	3885.7
2	0	25000	
3	0	0	
4	0	0	
5	0	25000	
6	0	0	
7	0	20000	
8	15000	0	
9	0	0	
10	15000	0	
11	15000	0	

Find minimum transportation cost from hatcheries to farms

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total			Capacity	y/n
H1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	-1.7E-07	75000	-0
H2	0	25000	0	0	25000	0	20000	0	0	0	0	0	0	70000	<=	75000	75000	1
H3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	75000	0
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	75000	0
Total	0	25000	0	0	25000	0	20000	0	0	0	0	0	0	70000	=	70000		1
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
	0	25000	0	0	25000	0	20000	0	0	0	0	0	0					1
Capacity	0	25000	0	0	25000	0	20000	0	0	0	0	0	0					
y/n	0	1	0	0	1	0	1	0	0	0	0	0	0	3				

Changing here

Capacity		Site		
H	75000	0.9333	Transportation cost	3388.3
F	25000	2.8		

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
H1	0.01	0.00	0.06	0.10	0.09	0.09	0.10	0.04	0.06	0.02	0.12	0.08	0.10
H2	0.12	0.10	0.04	0.00	0.02	0.02	0.02	0.06	0.03	0.11	0.03	0.02	0.01
H3	0.06	0.04	0.02	0.06	0.05	0.06	0.06	0.00	0.03	0.05	0.08	0.04	0.06
H4	0.13	0.12	0.06	0.03	0.02	0.04	0.05	0.08	0.06	0.13	0.00	0.04	0.01

Min. Transportation Cost,G17

Find min.Tr-Cost

Opened Site	C	F	Adjust F	H	Tr-cost C-F	Tr-Cost F-H	Tr-Cost
1	25000	0	0	0	3885.7	3388.3	7274
2	0	25000	25000	70000			
3	0	0	0	0			
4	0	0	0	0			
5	0	25000	25000				
6	0	0	0				
7	0	20000	20000				
8	15000	0	0				
9	0	0	0				
10	15000	0	0				
11	15000	0	0				
12		0	0				
13		0	0				
Total	70000	70000	70000	70000			7274
site	4	3	3	1			

Note: If assume linear, the program does not satisfy.

Cost

Fixed Cost	B/. 582,393
Variable Cost	B/. 2,149,000
Transportation Cost	B/. 7,274
Total Cost	B/. 2,738,667

Demand	70000
H-Supply	70000
F-Supply	70000
Fixed Cost	
Hatchery	B/. 36,243
Farming	B/. 182,050
Variable Cost	
Hatchery	1.08
Farming	29.62
Transportation Cost	
Farm to Customer	3885.7
Hatchery to Farm	3388.3
Location' site	
No. of Hatchery	1
No. of Farming	3

Medium demands: 115,000 units per month

Find minimum transportation cost from farms to customers.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total			Capacity	y/n		
F1	0	0	0	0	0	0	0	0	0	0	0	0	<=	2.2E-06	25000	0	<=	1
F2	0	5000	0	5000	5000	5000	0	0	5000	0	0	25000	<=	25000	25000	1	<=	1
F3	0	0	0	0	0	0	0	0	0	0	0	0	<=	-4E-44	25000	-0	<=	1
F4	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F5	0	0	0	0	0	0	0	0	0	0	0	0	<=	3.6E-08	25000	0	<=	1
F6	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.5E-13	25000	0	<=	1
F7	0	0	0	0	0	0	0	20000	0	0	0	20000	<=	25000	25000	1	<=	1
F8	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F9	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
F10	25000	0	0	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1	<=	1
F11	0	0	0	0	0	0	0	0	0	20000	0	20000	<=	25000	25000	1	<=	1
F12	5000	0	0	0	0	0	0	0	0	0	20000	25000	<=	25000	25000	1	<=	1
F13	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0	<=	1
Total	30000	5000	0	5000	5000	5000	0	20000	5000	20000	20000	115000				5		
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=		
Demand	30000	5000	0	5000	5000	5000	0	20000	5000	20000	20000	115000				5		

Cost of transportation from farming to customers (Baht/unit)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
F1	0.10	0.41	0.45	0.28	0.13	0.21	0.45	0.48	0.13	0.52	0.39
F2	0.07	0.34	0.38	0.23	0.11	0.13	0.38	0.41	0.08	0.45	0.32
F3	0.20	0.51	0.55	0.40	0.32	0.31	0.13	0.18	0.25	0.22	0.08
F4	0.36	0.66	0.70	0.55	0.47	0.46	0.09	0.07	0.40	0.13	0.09
F5	0.34	0.65	0.68	0.54	0.45	0.45	0.00	0.14	0.39	0.07	0.05
F6	0.34	0.65	0.69	0.54	0.46	0.45	0.10	0.08	0.39	0.18	0.08
F7	0.38	0.68	0.72	0.57	0.49	0.48	0.14	0.00	0.42	0.22	0.12
F8	0.11	0.43	0.47	0.32	0.24	0.23	0.22	0.25	0.16	0.29	0.15
F9	0.25	0.55	0.59	0.44	0.36	0.35	0.14	0.12	0.29	0.23	0.09
F10	0.07	0.38	0.42	0.27	0.14	0.18	0.42	0.45	0.11	0.49	0.36
F11	0.43	0.73	0.77	0.62	0.54	0.53	0.09	0.20	0.47	0.05	0.15
F12	0.28	0.59	0.62	0.48	0.39	0.39	0.05	0.12	0.33	0.12	0.00
F13	0.36	0.67	0.70	0.56	0.36	0.47	0.05	0.13	0.41	0.07	0.09

F	25000	Transportation Cost	8740.9
H	75000		
If			

minimize transportation cost,G41.

condition y/n <13

Solution is

	C	F	Tr-Cost
1	30000	0	8740.9
2	5000	25000	
3	0	0	
4	5000	0	
5	5000	0	
6	5000	0	
7	0	20000	
8	20000	0	
9	5000	0	
10	20000	25000	
11	20000	20000	

Find minimum transportation cost from hatcheries to farms

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total			Capacity	y/n
H1	0	25000	0	0	0	0	0	0	0	25000	0	0	0	50000	<=	75000	75000	1
H2	0	0	0	0	0	0	20000	0	0	0	20000	25000	0	65000	<=	75000	75000	1
H3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	3.08E-11	75000	0
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	-6.7E-07	75000	-0
Total	0	25000	0	0	0	0	20000	0	0	25000	20000	25000	0	115000		115000		2
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
	0	25000	0	0	0	0	20000	0	0	25000	20000	25000	0					2
Capacity	0	25000	0	0	0	0	20000	0	0	25000	20000	25000	0					
y/n	0	1	0	0	0	0	1	0	0	1	1	1	0	5				

Changing here

Capacity		Site		
H	75000	1.5333	Transportation cost	2007.4
F	25000	4.6		

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
H1	0.01	0.00	0.06	0.10	0.09	0.09	0.10	0.04	0.06	0.02	0.12	0.08	0.10
H2	0.12	0.10	0.04	0.00	0.02	0.02	0.02	0.06	0.03	0.11	0.03	0.02	0.01
H3	0.06	0.04	0.02	0.06	0.05	0.06	0.06	0.00	0.03	0.05	0.08	0.04	0.06
H4	0.13	0.12	0.06	0.03	0.02	0.04	0.05	0.08	0.06	0.13	0.00	0.04	0.01

Min. Transportation Cost,G17

Find min.Tr-Cost

Opened Site	C	F	Adjust F	H	Tr-cost C-F	Tr-Cost F-H	Tr-Cost
1	30000	0	0	50000	8740.9	2007.4	10748
2	5000	25000	25000	65000			
3	0	0	0	0			
4	5000	0	0	0			
5	5000	0	0				
6	5000	0	0				
7	0	20000	20000				
8	20000	0	0				
9	5000	0	0				
10	20000	25000	25000				
11	20000	20000	20000				
12		25000	25000				
13		0	0				
Total	115000	115000	115000	115000			10748
site	4	5	5	2			

Note: if assume linear, the program does not find solution

Cost

Fixed Cost	B/. 982,736
Variable Cost	B/. 3,530,500
Transportation Cost	B/. 10,748
Total Cost	B/. 4,523,984

Demand	115000
H-Supply	115000
F-Supply	115000
Fixed Cost	
Hatchery	B/. 36,243
Farming	B/. 182,050
Variable Cost	
Hatchery	1.08
Farming	29.62
Transportation Cost	
Farm to Customer	8740.9
Hatchery to Farm	2007.4
Location' site	
No. of Hatchery	2
No. of Farming	5

Medium demand: 160,000 units per month.

Find minimum transportation cost from farms to customers.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total			Capacity	y/n
F1	0	0	0	15000	10000	0	0	0	0	0	0	25000	<=	25000	25000	1
F2	0	10000	5000	0	0	10000	0	0	0	0	0	25000	<=	25000	25000	1
F3	0	0	0	0	0	0	0	0	0	0	0	0	<=	5.6E-12	25000	0
F4	0	0	0	0	0	0	0	0	0	0	0	0	<=	3.1E-28	25000	0
F5	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F6	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F7	0	0	0	0	0	0	0	20000	0	0	0	20000	<=	25000	25000	1
F8	20000	0	0	0	0	0	0	0	0	0	0	20000	<=	25000	25000	1
F9	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F10	15000	0	0	0	0	0	0	0	10000	0	0	25000	<=	25000	25000	1
F11	0	0	0	0	0	0	0	0	0	20000	0	20000	<=	25000	25000	1
F12	0	0	0	0	0	0	5000	0	0	0	20000	25000	<=	25000	25000	1
F13	0	0	0	0	0	0	0	0	0	0	0	0	<=	4.9E-12	25000	0
Total	35000	10000	5000	15000	10000	10000	5000	20000	10000	20000	20000	160000				7
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
Demand	35000	10000	5000	15000	10000	10000	5000	20000	10000	20000	20000	160000				7

Cost of transportation from farming to customers (Baht/unit)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
F1	0.10	0.41	0.45	0.28	0.13	0.21	0.45	0.48	0.13	0.52	0.39
F2	0.07	0.34	0.38	0.23	0.11	0.13	0.38	0.41	0.08	0.45	0.32
F3	0.20	0.51	0.55	0.40	0.32	0.31	0.13	0.18	0.25	0.22	0.08
F4	0.36	0.66	0.70	0.55	0.47	0.46	0.09	0.07	0.40	0.13	0.09
F5	0.34	0.65	0.68	0.54	0.45	0.45	0.00	0.14	0.39	0.07	0.05
F6	0.34	0.65	0.69	0.54	0.46	0.45	0.10	0.08	0.39	0.18	0.08
F7	0.38	0.68	0.72	0.57	0.49	0.48	0.14	0.00	0.42	0.22	0.12
F8	0.11	0.43	0.47	0.32	0.24	0.23	0.22	0.25	0.16	0.29	0.15
F9	0.25	0.55	0.59	0.44	0.36	0.35	0.14	0.12	0.29	0.23	0.09
F10	0.07	0.38	0.42	0.27	0.14	0.18	0.42	0.45	0.11	0.49	0.36
F11	0.43	0.73	0.77	0.62	0.54	0.53	0.09	0.20	0.47	0.05	0.15
F12	0.28	0.59	0.62	0.48	0.39	0.39	0.05	0.12	0.33	0.12	0.00
F13	0.36	0.67	0.70	0.56	0.36	0.47	0.05	0.13	0.41	0.07	0.09

F	25000	Transportation Cost	17955
H	75000		
If			

minimize transportation cost,G41.
condition y/n <13
Solution is

	C	F	Tr-Cost
1	35000	25000	17955
2	10000	25000	
3	5000	0	
4	15000	0	
5	10000	0	
6	10000	0	
7	5000	20000	
8	20000	20000	
9	10000	0	
10	20000	25000	
11	20000	20000	

Find minimum transportation cost from hatcheries to farms

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total			Capacity	y/n
H1	25000	25000	0	0	0	0	0	0	0	25000	0	0	0	75000	<=	75000	75000	1
H2	0	0	0	0	0	0	20000	0	0	0	20000	25000	0	65000	<=	75000	75000	1
H3	0	0	0	0	0	0	0	20000	0	0	0	0	0	20000	<=	75000	75000	1
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	75000	0
Total	25000	25000	0	0	0	0	20000	20000	0	25000	20000	25000	0	160000		160000		3
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
	25000	25000	0	0	0	0	20000	20000	0	25000	20000	25000	0					3
Capacity	25000	25000	0	0	0	0	20000	20000	0	25000	20000	25000	0					
y/n	1	1	0	0	0	0	1	1	0	1	1	1	0	7				

Changing here

Capacity		Site		
H	75000	2.1333	Transportation cost	2396
F	25000	6.4		

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
H1	0.01	0.00	0.06	0.10	0.09	0.09	0.10	0.04	0.06	0.02	0.12	0.08	0.10
H2	0.12	0.10	0.04	0.00	0.02	0.02	0.02	0.06	0.03	0.11	0.03	0.02	0.01
H3	0.06	0.04	0.02	0.06	0.05	0.06	0.06	0.00	0.03	0.05	0.08	0.04	0.06
H4	0.13	0.12	0.06	0.03	0.02	0.04	0.05	0.08	0.06	0.13	0.00	0.04	0.01

Min. Transportation Cost,G17

Find min.Tr-Cost

Opened Site	C	F	Adjust F	H	Tr-cost C-F	Tr-Cost F-H	Tr-Cost
1	35000	25000	25000	75000	17955	2396	20351
2	10000	25000	25000	65000			
3	5000	0	0	20000			
4	15000	0	0	0			
5	10000	0	0				
6	10000	0	0				
7	5000	20000	20000				
8	20000	20000	20000				
9	10000	0	0				
10	20000	25000	25000				
11	20000	20000	20000				
12		25000	25000				
13		0	0				
Total	160000	160000	160000	160000			20351
site	4	7	7	3			

Note: if assume liear, the program does not find solution.

Cost

Fixed Cost	B/. 1,383,079
Variable Cost	B/. 4,912,000
Transportation Cost	B/. 20,351
Total Cost	B/. 6,315,430

Demand	160000
H-Supply	160000
F-Supply	160000
Fixed Cost	
Hatchery	B/. 36,243
Farming	B/. 182,050
Variable Cost	
Hatchery	1.08
Farming	29.62
Transportation Cost	
Farm to Customer	17955
Hatchery to Farm	2396
Location' site	
No. of Hatchery	3
No. of Farming	7

Large demand: 205,000 units per month.

Find minimum transportation cost from farms to customers.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total			Capacity	y/n
F1	0	0	0	5000	20000	0	0	0	0	0	0	25000	<=	25000	25000	1
F2	0	0	10000	0	0	15000	0	0	0	0	0	25000	<=	25000	25000	1
F3	10000	15000	0	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1
F4	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F5	0	0	0	0	0	0	5000	0	0	20000	0	25000	<=	25000	25000	1
F6	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F7	0	0	0	0	0	0	0	20000	0	0	0	20000	<=	25000	25000	1
F8	25000	0	0	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1
F9	0	0	0	10000	0	0	0	0	0	0	0	10000	<=	25000	25000	1
F10	5000	0	0	0	0	0	0	0	20000	0	0	25000	<=	25000	25000	1
F11	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F12	0	0	0	0	0	0	5000	0	0	0	20000	25000	<=	25000	25000	1
F13	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
Total	40000	15000	10000	15000	20000	15000	10000	20000	20000	20000	20000	205000				9
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
Demand	40000	15000	10000	15000	20000	15000	10000	20000	20000	20000	20000	205000				9

Cost of transportation from farming to customers (Baht/unit)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
F1	0.10	0.41	0.45	0.28	0.13	0.21	0.45	0.48	0.13	0.52	0.39
F2	0.07	0.34	0.38	0.23	0.11	0.13	0.38	0.41	0.08	0.45	0.32
F3	0.20	0.51	0.55	0.40	0.32	0.31	0.13	0.18	0.25	0.22	0.08
F4	0.36	0.66	0.70	0.55	0.47	0.46	0.09	0.07	0.40	0.13	0.09
F5	0.34	0.65	0.68	0.54	0.45	0.45	0.00	0.14	0.39	0.07	0.05
F6	0.34	0.65	0.69	0.54	0.46	0.45	0.10	0.08	0.39	0.18	0.08
F7	0.38	0.68	0.72	0.57	0.49	0.48	0.14	0.00	0.42	0.22	0.12
F8	0.11	0.43	0.47	0.32	0.24	0.23	0.22	0.25	0.16	0.29	0.15
F9	0.25	0.55	0.59	0.44	0.36	0.35	0.14	0.12	0.29	0.23	0.09
F10	0.07	0.38	0.42	0.27	0.14	0.18	0.42	0.45	0.11	0.49	0.36
F11	0.43	0.73	0.77	0.62	0.54	0.53	0.09	0.20	0.47	0.05	0.15
F12	0.28	0.59	0.62	0.48	0.39	0.39	0.05	0.12	0.33	0.12	0.00
F13	0.36	0.67	0.70	0.56	0.36	0.47	0.05	0.13	0.41	0.07	0.09

F	25000	Transportation Cost	30909
H	75000		
If			

minimize transportation cost,G41.
condition y/n <13
Solution is

	C	F	Tr-Cost
1	40000	25000	30909
2	15000	25000	
3	10000	25000	
4	15000	0	
5	20000	25000	
6	15000	0	
7	10000	20000	
8	20000	25000	
9	20000	10000	
10	20000	25000	
11	20000	0	

Find minimum transportation cost from hatcheries to farms

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total			Capacity	y/n
H1	25000	25000	0	0	0	0	0	0	0	25000	0	0	0	75000	<=	75000	75000	1
H2	0	0	0	0	25000	0	20000	0	0	0	0	25000	0	70000	<=	75000	75000	1
H3	0	0	25000	0	0	0	0	25000	10000	0	0	0	0	60000	<=	75000	75000	1
H4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	75000	0
Total	25000	25000	25000	0	25000	0	20000	25000	10000	25000	0	25000	0	205000		205000		3
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
	25000	25000	25000	0	25000	0	20000	25000	10000	25000	0	25000	0					3
Capacity	25000	25000	25000	0	25000	0	20000	25000	10000	25000	0	25000	0					
y/n	1	1	1	0	1	0	1	1	1	1	0	1	0	9				

Changing here

Capacity		Site		
H	75000	2.7333	Transportation cost	3184.8
F	25000	8.2		

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
H1	0.01	0.00	0.06	0.10	0.09	0.09	0.10	0.04	0.06	0.02	0.12	0.08	0.10
H2	0.12	0.10	0.04	0.00	0.02	0.02	0.02	0.06	0.03	0.11	0.03	0.02	0.01
H3	0.06	0.04	0.02	0.06	0.05	0.06	0.06	0.00	0.03	0.05	0.08	0.04	0.06
H4	0.13	0.12	0.06	0.03	0.02	0.04	0.05	0.08	0.06	0.13	0.00	0.04	0.01

Min. Transportation Cost,G17

Find min.Tr-Cost

Opened Site	C	F	Adjust F	H	Tr-cost C-F	Tr-Cost F-H	Tr-Cost
1	40000	25000	25000	75000	30909	3184.8	34094
2	15000	25000	25000	70000			
3	10000	25000	25000	60000			
4	15000	0	0	0			
5	20000	25000	25000				
6	15000	0	0				
7	10000	20000	20000				
8	20000	25000	25000				
9	20000	10000	10000				
10	20000	25000	25000				
11	20000	0	0				
12		25000	25000				
13		0	0				
Total	205000	205000	205000	205000			34094
site	4	9	9	3			

Note: if assume linear, the program does not find the solution.

Cost

Fixed Cost	B/. 1,747,179
Variable Cost	B/. 6,293,500
Transportation Cost	B/. 34,094
Total Cost	B/. 8,074,773

Demand	205000
H-Supply	205000
F-Supply	205000
Fixed Cost	
Hatchery	B/. 36,243
Farming	B/. 182,050
Variable Cost	
Hatchery	1.08
Farming	29.62
Transportation Cost	
Farm to Customer	30909
Hatchery to Farm	3184.8
Location' site	
No. of Hatchery	3
No. of Farming	9

Large demand: 245,000 units per month.

Find minimum transportation cost from farms to customers.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	total			Capacity	y/n
F1	0	0	0	15000	10000	0	0	0	0	0	0	25000	<=	25000	25000	1
F2	0	5000	0	5000	0	15000	0	0	0	0	0	25000	<=	25000	25000	1
F3	10000	0	15000	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1
F4	0	0	0	0	0	0	0	0	0	0	0	0	<=	5.6E-13	25000	0
F5	0	0	0	0	0	0	20000	0	0	5000	0	25000	<=	25000	25000	1
F6	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F7	0	0	0	0	0	0	0	20000	0	0	0	20000	<=	25000	25000	1
F8	25000	0	0	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1
F9	0	15000	10000	0	0	0	0	0	0	0	0	25000	<=	25000	25000	1
F10	5000	0	0	0	0	0	0	0	20000	0	0	25000	<=	25000	25000	1
F11	0	0	0	0	0	0	0	0	0	0	0	0	<=	0	25000	0
F12	5000	0	0	0	0	0	0	0	0	0	20000	25000	<=	25000	25000	1
F13	0	0	0	0	10000	0	0	0	0	15000	0	25000	<=	25000	25000	1
Total	45000	20000	25000	20000	20000	15000	20000	20000	20000	20000	20000	245000				10
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
Demand	45000	20000	25000	20000	20000	15000	20000	20000	20000	20000	20000	245000				10

Cost of transportation from farming to customers (Baht/unit)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
F1	0.10	0.41	0.45	0.28	0.13	0.21	0.45	0.48	0.13	0.52	0.39
F2	0.07	0.34	0.38	0.23	0.11	0.13	0.38	0.41	0.08	0.45	0.32
F3	0.20	0.51	0.55	0.40	0.32	0.31	0.13	0.18	0.25	0.22	0.08
F4	0.36	0.66	0.70	0.55	0.47	0.46	0.09	0.07	0.40	0.13	0.09
F5	0.34	0.65	0.68	0.54	0.45	0.45	0.00	0.14	0.39	0.07	0.05
F6	0.34	0.65	0.69	0.54	0.46	0.45	0.10	0.08	0.39	0.18	0.08
F7	0.38	0.68	0.72	0.57	0.49	0.48	0.14	0.00	0.42	0.22	0.12
F8	0.11	0.43	0.47	0.32	0.24	0.23	0.22	0.25	0.16	0.29	0.15
F9	0.25	0.55	0.59	0.44	0.36	0.35	0.14	0.12	0.29	0.23	0.09
F10	0.07	0.38	0.42	0.27	0.14	0.18	0.42	0.45	0.11	0.49	0.36
F11	0.43	0.73	0.77	0.62	0.54	0.53	0.09	0.20	0.47	0.05	0.15
F12	0.28	0.59	0.62	0.48	0.39	0.39	0.05	0.12	0.33	0.12	0.00
F13	0.36	0.67	0.70	0.56	0.36	0.47	0.05	0.13	0.41	0.07	0.09

F	25000	Transportation Cost	46653
H	75000		
If			

minimize transportation cost,G41.
condition y/n <13
Solution is

	C	F	Tr-Cost
1	45000	25000	46653
2	20000	25000	
3	25000	25000	
4	20000	0	
5	20000	25000	
6	15000	0	
7	20000	20000	
8	20000	25000	
9	20000	25000	
10	20000	25000	
11	20000	0	

Find minimum transportation cost from hatcheries to farms

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	Total			Capacity	y/n
H1	25000	25000	0	0	0	0	0	0	0	25000	0	0	0	75000	<=	75000	75000	1
H2	0	0	0	0	0	0	20000	0	0	0	0	25000	25000	70000	<=	75000	75000	1
H3	0	0	25000	0	0	0	0	25000	25000	0	0	0	0	75000	<=	75000	75000	1
H4	0	0	0	0	25000	0	0	0	0	0	0	0	0	25000	<=	75000	75000	1
Total	25000	25000	25000	0	25000	0	20000	25000	25000	25000	0	25000	25000	245000	=	245000		4
	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=	>=					<=
	25000	25000	25000	0	25000	0	20000	25000	25000	25000	0	25000	25000					4
Capacity	25000	25000	25000	0	25000	0	20000	25000	25000	25000	0	25000	25000					
y/n	1	1	1	0	1	0	1	1	1	1	0	1	1	10				

Capacity		Site		
H	75000	3.2667	Transportation cost	3951.9
F	25000	9.8		

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
H1	0.01	0.00	0.06	0.10	0.09	0.09	0.10	0.04	0.06	0.02	0.12	0.08	0.10
H2	0.12	0.10	0.04	0.00	0.02	0.02	0.02	0.06	0.03	0.11	0.03	0.02	0.01
H3	0.06	0.04	0.02	0.06	0.05	0.06	0.06	0.00	0.03	0.05	0.08	0.04	0.06
H4	0.13	0.12	0.06	0.03	0.02	0.04	0.05	0.08	0.06	0.13	0.00	0.04	0.01

Min. Transportation Cost,G17

Find min.Tr-Cost

Opened Site	C	F	Adjust F	H	Tr-cost C-F	Tr-Cost F-H	Tr-Cost
1	45000	25000	25000	75000	46653	3951.9	50605
2	20000	25000	25000	70000			
3	25000	25000	25000	75000			
4	20000	0	0	25000			
5	20000	25000	25000				
6	15000	0	0				
7	20000	20000	20000				
8	20000	25000	25000				
9	20000	25000	25000				
10	20000	25000	25000				
11	20000	0	0				
12		25000	25000				
13		25000	25000				
Total	245000	245000	245000	245000			50605
site	11	10	10	4			

Cost

Fixed Cost	B/. 1,965,472
Variable Cost	B/. 7,521,500
Transportation Cost	B/. 50,605
Total Cost	B/. 9,537,577

Demand	245000
H-Supply	245000
F-Supply	245000
Fixed Cost	
Hatchery	B/. 36,243
Farming	B/. 182,050
Variable Cost	
Hatchery	1.08
Farming	29.62
Transportation Cost	
Farm to Customer	46653
Hatchery to Farm	3951.9
Location' site	
No. of Hatchery	4
No. of Farming	10