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MIXED INTEGER LINEAR PROGRAMMING MODEL FOR INTEGRATED FISH SUPPLY CHAIN PLANNING

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ABSTRACT

The Province of Aceh has many types of fish resources that become superior commodities, because most of Aceh's territory is located on the coastline which is the waters of an exclusive economic zone. There are several regencies and cities in Aceh province that are far from the coastline, thus experiencing a shortage of fish supply, therefore planning and management of fish supply chains is needed to anticipate uncertainty in fish supply for areas far from the coast. In the production planning strategy scenario, the mathematical programming model plays a very important role in balancing supply chain planning in decision making, so this research was conducted with an optimization approach using the Mixed Integer Linear Programming (MILP) method. The stages carried out in this study began data collection and literature review, determining parameters and decision variables, formulating the objective functions and constraints of the model, designing the model, implementing the model, testing and simulating the model. Model testing and simulations are carried out using the lindo program. The purpose of this research is to make a Mixed Integer Linear Programming optimization model for integrated fish supply chain planning, this model can help to solve the problem of fish supply shortages in certain areas, so that consumer demand for fish resources can be done quickly. The model of this research can also minimize the operational costs of the fish supply chain from suppliers to consumers. The results of this study are also expected to help decision makers and stakeholders related to the planning and management of fish resources in the province of Aceh.

Keywords: *Supply Chain, Optimization, Planning, Integrated, Fish*

1. INTRODUCTION

An intelligent decision model is needed for everyone, stakeholders and leaders. Decisions can be based on day-to-day or even momentary, many important decisions that come from the information available and the treatment of that information. Essentially, the more relevant information is needed, the higher the level of knowledge and the more intelligent decisions can be taken. Decisions made related to the planning and management of fish supply chains required the role of intelligent decision making systems, because this decision making process contains large data [1].

Fisheries are activities related to the management of the utilization of fish resources, ranging from production and processing to marketing carried out in a fisheries business system. Fish supply chain is a process of product activity so that it reaches consumers by involving several systems to support the process of fish distribution to their destination. The need for fish supply chains aims to meet the demand for fish in areas far from fish resources.

The fisheries product supply chain in the process involves several players, including fishermen, collectors, entrepreneurs and exporters. The fishery products produced have the characteristics of perishability and include types of products with short expiry [2] as well as being seasonal which depends on the environment with temperature and humidity being important factors [3], so to get to consumers, a good and adequate supply chain management system is needed. According to [4], [5], [6], [7] supply chain management is the process and overall production activities from processing and distribution activities, to the desired products to consumers or the public with the aim to improve product quality with minimum costs. In dealing with the above conditions, we need an artificial intelligence based model for integrated supply chains to support the industrial revolution era 4.0 [8].

The decision making process in the fish supply chain is very complex and the need for modeling increases [9], [10] can support strategy and implementation for high-performance supply chain network designs. This complexity is caused by the large number of variables and data [9]. n this regard, optimization has become a high technology in fish resource management planning, which in this connection is included in the supply chain [11], [12].

Besides this the mathematical optimization model represents a solid conceptual paradigm for analyzing and solving problems that arise in the integrated planning of the fish resource supply chain[11], [12]. The structure of integrated fish supply chain planning and management of the Mixed Integer Linear Programming (MILP) model can provide a mathematical optimization model framework to illustrate the characteristics of the problem. [13] explains the MILP model that integrates all components in the supply chain, namely: suppliers, distribution centers and consumers. [14] explain the computational MILP model that can solve two echelon supply chain problems, with uncertainty at the inventory level.

To produce an optimal solution to minimize the cost of the supply chain distribution network using the MILP method. The MILP method is a mathematical method to achieve the desired goals by considering the availability of available resources [15]. [16] argues that in a production planning strategy scenario, mathematical model programming plays a very important role in balancing supply chain planning in decision making. So this research was conducted with an optimal approach through the Mixed Integer Linear Programming method.

Mixed integer linear programming method is a simple method that can achieve optimal goals within the limits of available resources. mixed integer linear programming is a deterministic tool, which means that a model parameter is assumed to be known with certainty. This is probably the biggest weakness in mixed integer linear programming. In the industrial world, a production manager cannot accurately ascertain what will happen in the future. Besides the assumptions made are assumptions with linear functions, where in the industrial world there is no evidence that shows that the cost of industrial production is a linear function [17].

The data to be processed in the research problem of planning and management of integrated fish resources is large-scale data, so that the model discussed in the previous paragraph is still not suitable for large-scale management. This research is expected to produce an optimization model of integrated fish resource supply chain distribution network planning. This fish supply chain distribution network model can also be implemented using the ant colony algorithm approach to find the shortest route [18].

2. MILP METHOD

The settlement method used for the problem of planning and managing an integrated fish supply chain distribution network uses a proper direct search developed by Nam Hwang. With regard to the following Mixed Integer Linear Programming (MILP) problem:

$$\min \quad P = c^T x \tag{1}$$

$$\text{constraint } Ax \leq b \tag{2}$$

$$x \geq 0 \tag{3}$$

$$x_j \text{ integer for } j \in J \tag{4}$$

Components of basic optimal feasible vectors $(x_b)\ k$, to resolve the problem with the MILP it is written as follows:

$$(x_B)k = \beta_k - \alpha_{k1}(x_N)1 - \cdots - \alpha_{kj}(x_n)j - \cdots - \alpha_{kn} - m(x_N)n - m \tag{5}$$

Note that: the statement can be found in the final procedure of the simplex method. If $(X_B)k$ is an integer variable it can be assumed that β_k non integer, then partition β_k becomes a fractional component as well as an integer component given by:

$$\beta_k = [\beta_k] + f_k \quad 0 \leq f_k \leq 1 \tag{6}$$

Suppose you want to be able to add $(X_B)_k$ with respect to the nearest integer number, that is $([\beta] + 1)$. Based on the idea of a sub-optimal solution that is possible to raise a special non-basic variable, say $(X_N)_{J*}$ with the upper limit ie zero given α_{kj*} as an element of a vector Δ_{j*} is negative. If Δ_{j*} is the sum of non-variable displacement $(X_N)_{j*}$ so the numerical value of scalar $(X_N)_k$ is an integer value. Refer to equation (5), then Δ_{j*} can be stated as follows:

$$\Delta_{f*} = \frac{1 - f_k}{-\alpha_{kj*}} \tag{7}$$

Meanwhile the remaining non-basic variables are at zero. Can be seen after being substituted (7) in the equation (5) for $(X_N)_{j*}$ to calculate the partition from β_k in the equation (6) then obtained:

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$$(X_B)k = [\beta] + 1 \quad (8)$$

so that $(X_B)k$ is an integer. Thus it is clear that non-basic variables can play an important role in adding the corresponding basic variables. So the next result is necessary to ensure that non-integer variables can work in the sum and rounding process.

Theorem: Suppose the MILP problem is in the equation (1) - (5) have an optimal solution then the non-basic variable $(X_N)_{j*} = 1,\ldots,n$ must be an integer variable.

Proof: Troubleshooting as a continuous slack variable. Assuming that the vector is a basic variable X_B it consists of all slack variables, then all integer variables will be in a non-basic vector X_N because it is an integer value. Thus it is clear that the other components $(X_B)_{i\neq k}$ for vectors X_B will be fulfilled as the numerical value of the scalar $(X_N)_{j*}$and increase by Δ_{j*}. As a result the elements of the vector α_{j*} for example $i \neq k$ is positive, then the appropriate element of X_B will decrease and maybe even move past zero. Likewise, the vector component x must not move below zero, due to non negative boundaries. This formulation is called the minimum ratio test needed to see how the maximum movement from non-basic $(X_N)_{j*}$ so all components x still be feasible. The test ratio includes two cases, namely:

a. Basic variable, $(X_B)_{i\neq k}$ lower limit decreases to zero.
b. Basic variable, $(X_B)_k$ increases with integer values.

3. ALGORITHM

Suppose a continuous optimal solution can be partitioned as a round part and a fractional part

$$x = [x] + f, \quad 0 \leq f \leq 1$$

Where $[x]$ is an integer component of a fraction variable x and f is a fractional component [19], [20], [21].

Step 1. Select line $i*$ which is the smallest integer that is not worthy, so $\delta_{i*} = \min\{f_i, 1 - f_i\}$

Step 2. Perform pricing operations for non-basic transfers $v_{i*}^T = e_{i*}^T B^{-1}$

Step 3. Count $\sigma_{ij} = v_{i*}^T \alpha_j$ with j in corresponds to $\min_j \left\{ \left| \frac{d_j}{\sigma_{ij}} \right| \right\}$ calculate the maximum non-basic j ower limit and limit on. If not, continue to non-integer non-basic or superbasis j next, If there are. Column j^* raised from the limit bottom or derived from the upper limit. If not proceed to i^*

Step 4. Count $\alpha_{j*} = B^{-1}\alpha_{j*}$ solve $B\alpha_{j*} = \alpha_{j*}$ for α_{j*}

Step 5. Do a ratio test for the basic variable by releasing non-basic j^* from its limit.

Step 6. Basis exchange

Step 7. If column $i^*=\{\emptyset\}$ stop, if not repeat step 1.

4. RESEARCH METHODOLOGY

The steps taken in the research of the Mixed Integer Linear Programming (MILP) model for integrated fish supply chain planning, which are related to fish supply and distribution from suppliers to consumers, are as follows:

a. Literature review.
   Literature review was conducted to obtain literature and reference studies related to the optimization model of Mixed Integer Linear Programming and integrated fish supply chain planning.
b. Data collection.
   The research data used are supplier data on fish resources, transportation cost data from suppliers to distribution centers and to consumers, distribution route data, operational cost data for product inventory and other data. The data used in the form of numerical data in the form of a matrix.
c. Determine the parameters and decision variables.
   The determination of decision parameters and variables will be used to design objective function and model constraint functions.
d. Formulate the objective function of the model.
   The objective function of the model is to minimize the operational costs of the supply chain, namely to minimize transportation costs, minimize inventory costs and minimize other costs associated with the distribution of the fish supply chain network.
e. Formulate the constraint function of the model.
   Formulating the constraints of the model is done by determining the initial value of the problem and the limitations of the model to be built.
f. Modeling.
   This model formulation is used for optimal planning and decision making, then the structure of the model is in the form of a mathematical program model.
g. Model implementation and testing.
   The purpose of testing and simulation is to find out whether the model has run well as desired and if an error occurs in the model can be corrected immediately.

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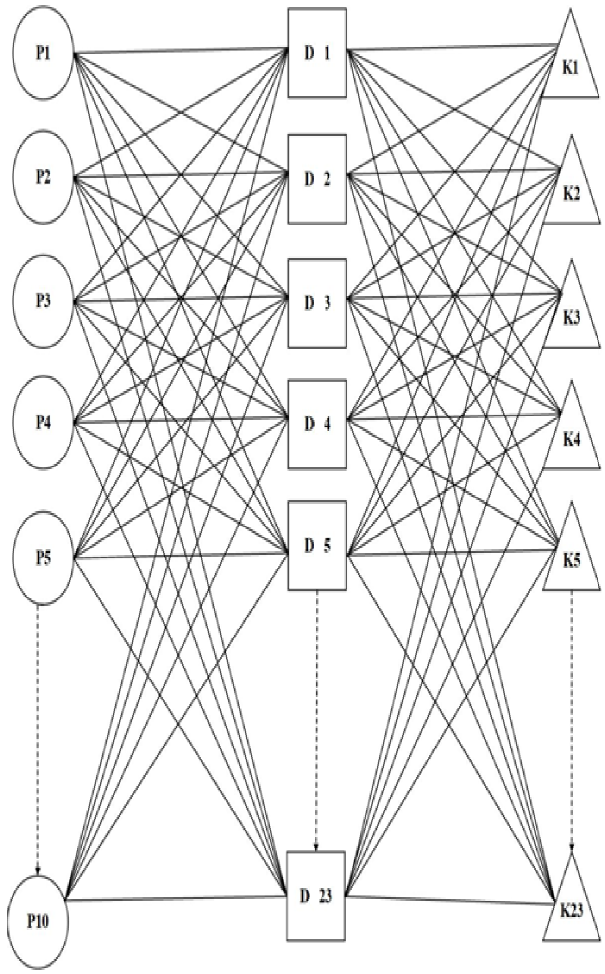
5. PROBLEM DESCRIPTION

As for the urgency of the problem from this research, because there are several regions in Aceh province that have a shortage of fish supply, because it is located far from the coastline, so that the distribution of fish from suppliers to the community takes a long time, a good distribution model is needed, with the right time so that the quality of fish remains good with a minimal cost. Mixed Integer Linear Programming Model for integrated fish supply chain planning is one solution to solve this problem. The existence of this model is expected to be able to help solve problems in intelligent decision making related to policies for fish planning and management, specifically the problem of fish distribution networks. This model is expected to maximize fish resources for consumer needs by minimizing costs, namely:

a. Minimize costs for selecting supplier locations $p \in P$ from several existing suppliers.
b. Minimize travel costs or transportation costs to the supplier place $p \in P$ by using the shortest route $v \in V$.
c. Minimize travel costs or transportation costs from suppliers $p \in P$ chosen to the distribution site $d \in D$ by using a route $v \in V$ shortest.
d. Minimize travel costs or transportation costs from distribution points $d \in D$ to the place of consumers $k \in K$ by using a route $v \in V$ shortest.
e. Minimizing the cost of fish product inventory $m \in M$ at the supplier's place $p \in P$ the chosen.
f. Minimizing the cost of fish product inventory $m \in M$ at the distribution site $d \in D$ the chosen.

6. MATHEMATICAL MODEL FORMULATION

The mathematical model built is based on the integrated fish supply chain planning model, which consists of fish supply places from 10 fish landing bases, while distribution and consumer sites come from 23 regions in Aceh province, as shown in Figure 1.



P1..P10 : Fish Supplier Place
D1..D23: Distribution Place
K1..K23: Consumer

Figure 1: Fish supply chain network planning

There are several types of fishery commodities that become leading commodities in Aceh Province, namely: pelangis fish species, demersal fish species and reef fish species [1]. This commodity or product is stated in an index form $\ell = \in 1, -, M |$ Each type of commodity is assumed to take the supply chain diagram as it is illustrated 1. The notation used in the mathematical model formulation is as follows:

a. Set

P = Suppliers, index p
D = Distribution, index d
K = Consumer, index k
M = Fish Products, index m
V = Vehicle Routes, index v

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b. Parameter

BT_{pd}^{vm} = Transportation costs of fish products using the route $v \in V$ from the supplier's place $p \in P$ to the distribution site $d \in D$

BT_{vm}^{dk} = Transportation costs of fish products using the route $v \in V$ from the distribution site $d \in D$ to the place of consumers $k \in K$

C_{pm} = The operational costs of storing fish products at the supplier $p \in P$

C_{md} = Costs for the operational storage of fish products at distribution sites $d \in D$

BT_p = Costs associated with choosing a supplier's place $p \in P$

BT_{pv} = Transportation costs associated with the supplier's place $p \in P$ use route $v \in V$

KP_p = Supplier place capacity $p \in P$

KD_d = Distribution capacity $d \in D$

JP_p^m = Total production of fish products $m \in M$ by the supplier $p \in P$

PP_k^m = Demand for fish products $m \in M$ by consumers $k \in K$

c. Decision Variable

R_{pd}^{vm} = The amount of fish products $m \in M$ will be shipped from the supplier's place $p \in P$ to the distribution site $d \in D$ use route $v \in V$

S_{vm}^{dk} = The amount of fish products $m \in M$ will be sent from the distribution point $d \in D$ to the place of consumers $k \in K$ use route $v \in V$

PA_{pm} = Initial inventory of fish products $m \in M$ at the supplier's place $p \in P$

PA_{md} = Initial inventory of fish products $m \in M$ at the distribution site $d \in D$

d. Binary variable

a_{kpv} = Binary variable worth 1, if consumers $k \in K$ visited from supplier's place $p \in P$ use route $v \in V$, is worth 0 if not.

X_p = Binary variable worth 1, if a supplier's place $p \in P$ selected, is worth 0 if not.

Y_{pv} = Binary variable worth 1, if route $v \in V$ used to visit supplier's place $p \in P$, is worth 0 if not.

7. RESULT AND DISCUSSION

7.1 Fish Supply Chain Optimization Model

Formulate a model for optimizing the planning and management of the fish resource supply chain distribution network in Aceh Province. Because this model is used for optimal planning and decision making, the structure of the model is in the form of a mathematical program model, which in general can be formulated as:

$$\text{Minimum} \quad v = w(x) \tag{9}$$

$$\text{constraint} \quad h(x) = J \tag{10}$$

$$x \geq 0 \tag{11}$$

Expression (1) states an objective function which in this case will minimize the function $w(x)$. Usually in reality there are always limitations on the decision variable x. Equation (2) expresses these limitations. Whereas statement (3) to limit that all values of the decision variable must be non-negative. In this condition variable x also called a continuous variable, which is a variable that can take all the values in a dimensionless real number space n (written as R^n)

In the problem of fish supply chain planning to be solved besides continuous variables there is also a binary variable, which is a variable that can be valued at 1 (yes) or 0 (no). At the beginning of modeling, an objective function is formulated. For the problem of planning and managing the supply chain design, the main objective to be achieved is to minimize costs. Therefore, based on the previously defined notation, the mathematical formulation of the objective function of fish supply chain planning can be stated as follows.

$$Minimum \sum_{p\in P} BT_p X_p + \sum_{p\in P}\sum_{v\in V} BT_{pv} Y_{pv} + \sum_{p\in P}\sum_{d\in D}\sum_{m\in M}\sum_{v\in V} BT_{pd}^{vm} R_{pd}^{vm} + \sum_{d\in D}\sum_{k\in K}\sum_{m\in M}\sum_{v\in V} BT_{vm}^{dk} S_{vm}^{dk} + \sum_{p\in P}\sum_{m\in M} C_{pm} PA_{pm} + \sum_{m\in M}\sum_{d\in D} C_{md} PA_{md} \tag{12}$$

Next is the formulation of the constraint functions of the fish supply chain network planning problem. With the constraint function as follows:

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$$\sum_{p\in P}\sum_{v\in V} a_{kpv} Y_{kpv} = 1 \quad \forall k \in K \tag{13}$$

$$X_p - Y_{pv} \geq 0 \quad \forall p \in P, v \in V \tag{14}$$

$$\sum_{p\in P}\sum_{m\in M} R_{pd}^{m} \leq \sum_{p\in P}\sum_{m\in M} KP_{pd}^{m} \qquad \forall d \in D \tag{15}$$

$$\sum_{p\in P}\sum_{m\in M} R_{pd}^{m} \geq \sum_{d\in D}\sum_{m\in M} S_{dk}^{m} \qquad \forall_k \in K \tag{16}$$

$$\sum_{d\in D}\sum_{m\in M} S_{m}^{dk} \leq \sum_{d\in D}\sum_{m\in M} KD_{m}^{d} \qquad \forall k \in K \tag{17}$$

$$\sum_{k\in K}\sum_{m\in M} S_{m}^{dk} = \sum_{k\in K}\sum_{m\in M} PP_{m}^{k} \qquad \forall d \in D \tag{18}$$

$$\sum_{p\in P}\sum_{m\in M} PA_{p}^{m} = \sum_{d\in D}\sum_{m\in M} PA_{d}^{m} + \sum_{p\in P}\sum_{m\in M} JP_{p}^{m} - \sum_{p\in P}\sum_{m\in M} R_{pd}^{m} \quad \forall_d \in D \tag{19}$$

$$\sum_{d\in D}\sum_{m\in M} PA_{d}^{m} = \sum_{d\in D}\sum_{m\in M} PA_{d}^{m} + \sum_{p\in P}\sum_{m\in M} R_{pd}^{m} - \sum_{d\in D}\sum_{m\in M} S_{m}^{dk} \quad \forall_k \in K \tag{20}$$

$$R_{pd}^{vm}, S_{\leq dk}^{vm}, PA_{pm}, PA_{pd} \geq 0 \qquad \forall p \in P, d \in D, m \in M, v \in V \tag{21}$$

Equation (12) through equation (21) is an optimization model of Mixed Integer Linear Programming for planning integrated fish supply chain distribution networks. Equation (12) states the objective function of the model, aiming to minimize the operational costs of the fish supply chain.

Constraint (13) states each supplier $p \in P$ use the route $v \in V$ to visit consumers $k \in K$ once. Constraint (14) states the supplier's place $p \in P$ selected by route $v \in V$ to visit a facility equal to zero. Constraint (15) states the number of fish products $m \in M$ from the supplier's place $p \in P$ to the distribution site $d \in D$ does not exceed the capacity of the supplier $p \in P$. Constraint (16) states the number of fish products $m \in M$ from the supplier's place $p \in P$ to the distribution site $d \in D$ must not be greater than the amount of fish products $m \in M$ sent from the distribution point $d \in D$ to the place of consumers $k \in K$. Constraint (17) states the number of fish products $m \in M$ from the distribution site $d \in D$ to the place of consumers $k \in K$ may not exceed the capacity of the distribution site $d \in D$. Constraint (18) states the number of fish products $m \in M$ from the distribution site $d \in D$ to the place of consumers $k \in K$ meet the demand for fish products $m \in M$ by consumers $k \in K$. Constraint (19) states the total initial inventory of fish products $m \in M$ to the supplier $p \in P$ consists of an initial inventory of fish products $m \in M$ at the distribution site $d \in D$ plus the number of supplier production $p \in P$ and subtracted by the amount of fish products $m \in M$ shipped from the supplier's place $p \in P$ to the distribution site $d \in D$. Constraint (20) states the total initial inventory of fish products $m \in M$ at the distribution site $d \in D$ consists of the initial inventory of distribution sites $d \in D$ plus the amount of fish products $m \in M$ sent from the supplier's place $p \in P$ to the distribution site $d \in D$ deducted by the amount of fish products $m \in M$ sent from the distribution point $d \in D$ to consumers $k \in K$. Constraint (21) states the range of binary variable values using binary integers, that is 0 and 1, assign value of decision variables worth integers.

7.2 Data Colection

The data used in this study is numerical data in the form of a matrix, so it can support the process of making mathematical calculation models by using the minimum functions as follows:

Table 1: Supplier selection cost data

BT-xp	p = 1	p = 2	p = 3	p = 4	p = 5
x = 1	2	2	2	1	4
x = 2	2	3	5	5	2
x = 3	2	5	1	5	1
x = 4	1	2	5	1	5
x = 5	1	3	5	5	4
In units of 100,000					

Table 2: Data on transportation costs to suppliers passing the route

BT- pv	v = 1	v = 2	v = 3	v = 4	v = 5
p = 1	3	3	3	3	2
p = 2	3	4	1	4	5
p = 3	4	3	5	1	5
p = 4	3	4	3	5	5
p = 5	3	3	3	4	5
In units of 100,000					

Table 3: Transportation cost data from suppliers to distribution centers

BT- pd	d = 1	d = 2	d = 3	d = 4	d = 5
p = 1	4	4	4	1	2
p = 2	5	5	5	4	5
p = 3	5	1	3	2	2
p = 4	3	5	4	2	5
p = 5	3	1	5	3	5
In units of 100,000					

Table 4: Transportation cost data from distribution centers to consumers

BT- dk	k = 1	k = 2	k = 3	k = 4	k = 5
d = 1	4	4	5	1	5
d = 2	3	2	1	1	2
d = 3	5	5	1	2	1
d = 4	3	3	2	5	4
d = 5	4	2	1	4	3
In units of 100,000					

Table 5: Data on operational costs of product inventory at suppliers

BT- pm	m = 1	m = 2	m = 3	m = 4	m = 5
p = 1	3	3	4	1	3
p = 2	4	5	2	5	2
p = 3	5	5	3	3	5
p = 4	4	2	3	3	2
p = 5	1	3	1	4	4
In units of 100,000					

Table 6: Data on operational costs of product suppliers at the distribution center

BT- dm	m = 1	m = 2	m = 3	m = 4	m = 5
d = 1	2	2	4	5	3
d = 2	1	1	5	1	2
d = 3	5	2	4	2	1
d = 4	1	1	2	2	2
d = 5	3	5	2	3	4
In units of 100,000					

7.3 Model Implementation

Calculation of the implementation of mathematical models in this study using the LINDO program. The implementation of this model is to minimize the operational costs of the fish supply chain from suppliers, distribution and consumers, as follows: minimizing the cost of selecting suppliers $p \in P$, minimize transportation costs to the supplier $p \in P$, minimize transportation costs from the supplier $p \in P$ to the distribution site $d \in D$, minimize transportation costs from distribution sites $d \in D$ to the place of consumers $k \in K$, minimize the cost of fish product inventory $m \in M$ at the supplier $p \in P$, minimize the cost of fish product inventory $m \in M$ at the distribution site $d \in D$. The following is a mathematical model calculation:

Operational costs of selecting a supplier $p \in P$
2 xp11 + 2 xp12 + 2 xp13 + 1 xp14 + 4 xp15
+ 2 xp21 + 3 xp22 + 5 xp23 + 5 xp24 + 2 xp25
+ 2 xp31 + 5 xp32 + 1 xp33 + 5 xp34 + 1 xp35
+ 1 xp41 + 2 xp42 + 5 xp43 + 1 xp44 + 5 xp45
+ 1 xp51 + 3 xp52 + 5 xp53 + 5 xp54 + 4 xp55

Operational costs of transportation to the supplier's place $p \in P$ using the route $v \in V$
+ 3 pv11 + 3 pv12 + 3 pv13 + 3 pv14 + 2 pv15
+ 3 pv21 + 4 pv22 + 1 pv23 + 4 pv24 + 5 pv25
+ 4 pv31 + 3 pv32 + 5 pv33 + 1 pv34 + 5 pv35
+ 3 pv41 + 4 pv42 + 3 pv43 + 5 pv44 + 5 pv45
+ 3 pv51 + 3 pv52 + 3 pv53 + 4 pv54 + 5 pv55

Operational costs of transportation from the supplier $p \in P$ to the distribution point $d \in D$
+ 4 pd11 + 4 pd12 + 4 pd13 + 1 pd14 + 2 pd15
+ 5 pd21 + 5 pd22 + 5 pd23 + 4 pd24 + 5 pd25
+ 5 pd31 + 1 pd32 + 3 pd33 + 2 pd34 + 2 pd35
+ 3 pd41 + 5 pd42 + 4 pd43 + 2 pd44 + 5 pd45
+ 3 pd51 + 1 pd52 + 5 pd53 + 3 pd54 + 5 pd55

Operational costs of transportation from distribution $d \in D$ to consumer areas $k \in K$
+ 4 dk11 + 4 dk12 + 5 dk13 + 1 dk14 + 5 dk15
+ 5 dk21 + 2 dk22 + 1 dk23 + 1 dk24 + 2 dk25
+ 5 dk31 + 5 dk32 + 1 dk33 + 2 dk34 + 1 dk35
+ 3 dk41 + 3 dk42 + 2 dk43 + 5 dk44 + 4 dk45
+ 3 dk51 + 2 dk52 + 1 dk53 + 4 dk54 + 3 dk55

Operational costs for fish product inventory $m \in M$ at supplier sites $p \in P$
+ 3 pm11 + 3 pm12 + 4 pm13 + 1 pm14 + 3 pm15
+ 4 pm21 + 5 pm22 + 2 pm23 + 5 pm24 + 2 pm25
+ 5 pm31 + 5 pm32 + 3 pm33 + 3 pm34 + 5 pm35
+ 4 pm41 + 2 pm42 + 3 pm43 + 3 pm44 + 2 pm45
+ 1 pm51 + 3 pm52 + 1 pm53 + 4 pm54 + 4 pm55

Operational costs for fish product inventory $m \in M$ at distribution sites $d \in D$
+ 2 dm11 + 2 dm12 + 4 dm13 + 5 dm14 + 3 dm15
+ 1 dm21 + 1 dm22 + 5 dm23 + 1 dm24 + 2 dm25
+ 5 dm31 + 2 dm32 + 4 dm33 + 2 dm34 + 1 dm35
+ 1 dm41 + 1 dm42 + 2 dm43 + 2 dm44 + 2 dm45
+ 3 dm51 + 5 dm52 + 2 dm53 + 3 dm54 + 4 dm55

7.4 Model Testing Results

The following are the results of testing and simulating the model using the lindo program. The results obtained from testing with the maximum value for the objective function are 26 in the 10th iteration. The complete results of the optimum decision variable values in table 7.

Table 7: Optimum decision variable values

Variable	Value	Reduced Cost
XP11	0.00	2.00
XP12	0.00	2.00
XP13	0.00	2.00
XP14	0.00	1.00
XP15	0.00	4.00

XP21	0.00	2.00
XP22	0.00	3.00
XP23	0.00	5.00
XP24	0.00	5.00
XP25	0.00	2.00
XP31	0.00	2.00
XP32	0.00	5.00
XP33	0.00	1.00
XP34	0.00	5.00
XP35	0.00	1.00
XP41	0.00	1.00
XP42	0.00	2.00
XP43	0.00	5.00
XP44	0.00	1.00
XP45	0.00	5.00
PV11	0.00	1.00
PV12	0.00	1.00
PV13	0.00	1.00
PV14	0.00	1.00
PV15	1.00	0.00
PV21	0.00	2.00
PV22	0.00	3.00
PV23	1.00	0.00
PV24	0.00	3.00
PV25	0.00	4.00
PV31	0.00	3.00
PV32	0.00	2.00
PV33	0.00	4.00
PV34	1.00	0.00
PV35	0.00	4.00
PV41	0.00	0.00
PV42	0.00	1.00
PV43	1.00	0.00
PV44	0.00	2.00
PV45	0.00	2.00
PD11	0.50	0.00
PD12	0.50	0.00
PD13	1.00	0.00
PD14	5.00	0.00
PD15	1.50	0.00
PD21	0.00	5.00
PD22	0.00	5.00
PD23	0.00	5.00
PD24	0.00	4.00
PD25	0.00	5.00
PD31	0.00	5.00
PD32	0.00	1.00
PD33	0.00	3.00
PD34	0.00	2.00
PD35	0.00	2.00
PD41	0.00	3.00
PD42	0.00	5.00
PD43	0.00	4.00
PD44	0.00	2.00
PD45	0.00	5.00
DK11	0.00	4.00
DK12	0.00	4.00
DK13	0.00	5.00
DK14	0.00	1.00
DK15	0.00	5.00
DK21	0.00	5.00
DK22	0.00	2.00
DK23	0.00	1.00
DK24	0.00	1.00
DK25	0.00	2.00
DK31	0.00	5.00
DK32	0.00	5.00
DK33	0.00	1.00
DK34	0.00	2.00
DK35	0.00	1.00
DK41	0.00	3.00
DK42	0.00	3.00
DK43	0.00	2.00
DK44	0.00	5.00
DK45	0.00	4.00
PM11	0.00	3.00
PM12	0.00	3.00
PM13	0.00	4.00
PM14	0.00	1.00
PM15	0.00	3.00
PM21	0.00	4.00
PM22	0.00	5.00

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PM23	0.00	2.00
PM24	0.00	5.00
PM25	0.00	2.00
PM31	0.00	5.00
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PM35	0.00	5.00
PM41	0.00	4.00
PM42	0.00	2.00
PM43	0.00	3.00
PM44	0.00	3.00
PM45	0.00	2.00
DM11	0.00	2.00
DM12	0.00	2.00
DM13	0.00	4.00
DM14	0.00	5.00
DM15	0.00	3.00
DM21	0.00	1.00
DM22	0.00	1.00
DM23	0.00	5.00
DM24	0.00	1.00
DM25	0.00	2.00
DM31	0.00	5.00
DM32	0.00	2.00
DM33	0.00	4.00
DM34	0.00	2.00
DM35	0.00	1.00
DM41	0.00	1.00
DM42	0.00	1.00
DM43	0.00	2.00
DM44	0.00	2.00
DM45	0.00	2.00

The following are the results of testing and simulating the model in sensitivity analysis. the variable column states the decision variable, the current coefficient column states the objective function coefficient, the allowable increase column states the value addition limit, so the optimum value does not change from the decision variable, while the allowable decrease column states the decrease limit so the optimum value does not change from the decision variable. The complete results in table 8 are based on the 10th iteration.

Table 8: Sensitivity Analysis

Variable	Current Coef	Allowable Increase	Allowable Decrease
XP11	2.00	INFINITY	2.00
XP12	2.00	INFINITY	2.00
XP13	2.00	INFINITY	2.00
XP14	1.00	INFINITY	1.00
XP15	4.00	INFINITY	4.00
XP21	2.00	INFINITY	2.00
XP22	3.00	INFINITY	3.00
XP23	5.00	INFINITY	5.00
XP24	5.00	INFINITY	5.00
XP25	2.00	INFINITY	2.00
XP31	2.00	INFINITY	2.00
XP32	5.00	INFINITY	5.00
XP33	1.00	INFINITY	1.00
XP34	5.00	INFINITY	5.00
XP35	1.00	INFINITY	1.00
XP41	1.00	INFINITY	1.00
XP42	2.00	INFINITY	2.00
XP43	5.00	INFINITY	5.00
XP44	1.00	INFINITY	1.00
XP45	5.00	INFINITY	5.00
PV11	3.00	INFINITY	1.00
PV12	3.00	INFINITY	1.00
PV13	3.00	INFINITY	1.00
PV14	3.00	INFINITY	1.00
PV15	2.00	INFINITY	INFINITY
PV21	3.00	INFINITY	2.00
PV22	4.00	INFINITY	3.00
PV23	1.00	2.00	INFINITY
PV24	4.00	INFINITY	3.00
PV25	5.00	INFINITY	4.00
PV31	4.00	INFINITY	3.00
PV32	3.00	INFINITY	2.00
PV33	5.00	INFINITY	4.00
PV34	1.00	2.00	INFINITY
PV35	5.00	INFINITY	4.00
PV41	3.00	INFINITY	0.00
PV42	4.00	INFINITY	1.00
PV43	3.00	0.00	INFINITY
PV44	5.00	INFINITY	2.00
PV45	5.00	INFINITY	2.00
PD11	4.00	INFINITY	4.00
PD12	4.00	INFINITY	4.00
PD13	4.00	INFINITY	4.00
PD14	1.00	INFINITY	1.00
PD15	2.00	INFINITY	2.00
PD21	5.00	INFINITY	5.00
PD22	5.00	INFINITY	5.00

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PD25	5.00	INFINITY	5.00
PD31	5.00	INFINITY	5.00
PD32	1.00	INFINITY	1.00
PD33	3.00	INFINITY	3.00
PD34	2.00	INFINITY	2.00
PD35	2.00	INFINITY	2.00
PD41	3.00	INFINITY	3.00
PD42	5.00	INFINITY	5.00
PD43	4.00	INFINITY	4.00
PD44	2.00	INFINITY	2.00
PD45	5.00	INFINITY	5.00
DK11	4.00	INFINITY	4.00
DK12	4.00	INFINITY	4.00
DK13	5.00	INFINITY	5.00
DK14	1.00	INFINITY	1.00
DK15	5.00	INFINITY	5.00
DK21	5.00	INFINITY	5.00
DK22	2.00	INFINITY	2.00
DK23	1.00	INFINITY	1.00
DK24	1.00	INFINITY	1.00
DK25	2.00	INFINITY	2.00
DK31	5.00	INFINITY	5.00
DK32	5.00	INFINITY	5.00
DK33	1.00	INFINITY	1.00
DK34	2.00	INFINITY	2.00
DK35	1.00	INFINITY	1.00
DK41	3.00	INFINITY	3.00
DK42	3.00	INFINITY	3.00
DK43	2.00	INFINITY	2.00
DK44	5.00	INFINITY	5.00
DK45	4.00	INFINITY	4.00
PM11	3.00	INFINITY	3.00
PM12	3.00	INFINITY	3.00
PM13	4.00	INFINITY	4.00
PM14	1.00	INFINITY	1.00
PM15	3.00	INFINITY	3.00
PM21	4.00	INFINITY	4.00
PM22	5.00	INFINITY	5.00
PM23	2.00	INFINITY	2.00
PM24	5.00	INFINITY	5.00
PM25	2.00	INFINITY	2.00
PM31	5.00	INFINITY	5.00
PM32	5.00	INFINITY	5.00
PM33	3.00	INFINITY	3.00
PM34	3.00	INFINITY	3.00
PM35	5.00	INFINITY	5.00
PM41	4.00	INFINITY	4.00
PM42	2.00	INFINITY	2.00
PM43	3.00	INFINITY	3.00
PM44	3.00	INFINITY	3.00
PM45	2.00	INFINITY	2.00
DM11	2.00	INFINITY	2.00
DM12	2.00	INFINITY	2.00
DM13	4.00	INFINITY	4.00
DM14	5.00	INFINITY	5.00
DM15	3.00	INFINITY	3.00
DM21	1.00	INFINITY	1.00
DM22	1.00	INFINITY	1.00
DM23	5.00	INFINITY	5.00
DM24	1.00	INFINITY	1.00
DM25	2.00	INFINITY	2.00
DM31	5.00	INFINITY	5.00
DM32	2.00	INFINITY	2.00
DM33	4.00	INFINITY	4.00
DM34	2.00	INFINITY	2.00
DM35	1.00	INFINITY	1.00
DM41	1.00	INFINITY	1.00
DM42	1.00	INFINITY	1.00
DM43	2.00	INFINITY	2.00
DM44	2.00	INFINITY	2.00
DM45	2.00	INFINITY	2.00
DM51	2.00	INFINITY	3.00
DM52	2.00	INFINITY	5.00
DM53	4.00	INFINITY	2.00
DM54	5.00	INFINITY	3.00
DM55	3.00	INFINITY	4.00

The following are the results of testing and simulating the model in the slack or surplus process. If slack or surplus is zero, then it is grouped into active constraints. If the slack or surplus is not zero, then the constraints are grouped into inactive constraints, as in line 6, the constraints are active constraints with a dual price that has a positive value of 3.00. Complete results in table 9.

Table 9: Slack or Surplus

Row	Slack Or Surplus	Dual Prices
2)	0,00	-2.00
3)	0,00	-1.00
4)	0,00	-1.00
5)	0,00	-3.00
6)	0,00	3.00
7)	0,00	0,00
8)	0,00	0,00
9)	0,00	0,00
10)	0,00	0,00
11)	0,00	0,00
12)	0,00	-1,00
13)	0,00	-1.00
14)	0,00	-1,00
15)	0,00	-1,00
16)	0,00	-1.00

Sensitivity Analysis Graph, the results of testing the model with the lindo program in figure 2.

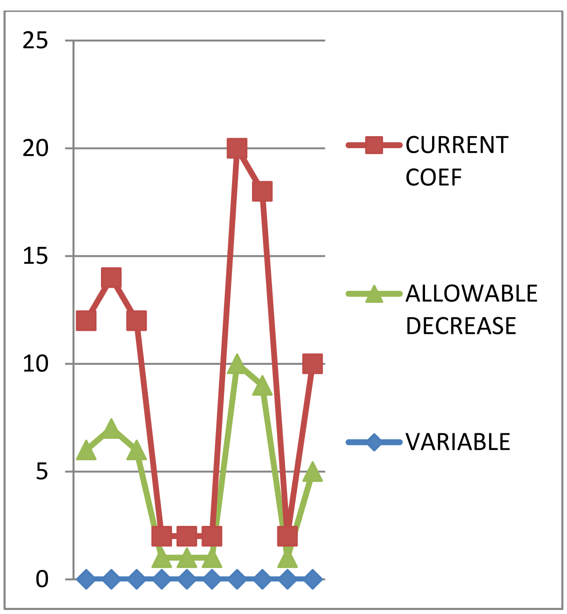

Figure 2: Sensitivity Analysis Graph

8. CONCLUSIONS

The mixed integer linear programming model for fish supply chain planning is an integrated optimization model for fish distribution network planning from suppliers that produce fish resources, then sent to consumers for areas that lack fish supply. This model is an optimization model to minimize the operational costs of fish supply chains, namely: minimizing transportation costs to suppliers, minimizing transportation costs from suppliers to distribution centers and minimizing transportation costs from distribution centers to consumers, minimizing product inventory costs to suppliers and to distribution centers. From the results of testing and simulating the model using the lindo program, the maximum value of the objective function is 26.00000 in the 10th iteration.

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