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## A push strategy optimization model for a marine shrimp farming supply chain network

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**Abstract:** Marine shrimp farming operations in Southeast Asia are still traditional and need to be improved in efficiency. In this paper, we first model a marine shrimp supply chain network, which consists of suppliers, farms, distribution centres, traders, and consumers. We also develop a mixed-integer linear programming under the push strategy framework in order to maximize the farmer's profit. Through a sensitivity analysis, we examine how the increase in costs affects the profits. The computational results are presented to demonstrate the feasibility of a real case of smart marine shrimp farming.

**Keywords:** push strategy; supply chain network; mixed-integer linear programming; marine shrimp farming; giant freshwater prawns

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### 1 Introduction

Marine shrimp farming is a century-old practice in many Asian countries. In Southeast Asia the main farming operations are still traditional. Due to a high demand for products and the low acquisition cost of land, these traditional farms are still commercially profitable even without advanced techniques (Fisheries and Aquaculture Department, 2017).

Giant freshwater prawn farming is one of the main types of marine shrimp farming. In Thailand, 90% of the prawn yield is for domestic consumption and 10% for export (Office of Agricultural Economics, 2011). Most of the giant freshwater prawn farms are located in the Central and Western regions such as Nakhon Pathom, Supanburi and Rachaburi province. These farms are often faced with such problems as managing the large volume of prawns, selecting suppliers for the purchase of prawn feed and deciding on the optimum number of truck trips.

Today, supply chain management (SCM) has become one of the most popular and the fastest growing areas in management. One major issue of SCM is the proper design of supply chains to serve customers effectively and efficiently (Poiger, 2010). SCM has gained importance in the sector of agricultural food management. Food supply chains are composed of organizations involved in the production and the distribution of food (Zuurbier et al., 1996). The main point that differentiates a food supply chain from other supply chains is its purpose, which is to guarantee the provision of safe and healthy products that are fully traceable from farm to fork (Bourlakis, and Weightman, 2004).

A typical supply chain network (SCN) involves a range variety of echelons: customers, retailers, distributors, manufacturers and raw material suppliers, all of which are connected through the flow of products, information and funds (Chopra and Meindl, 2013). Setting the right SCN strategy is vital for companies competing in the market (Lee 2002), and push strategy is one of the strategies. It is initiated and carried out in anticipation of customer demands. The production decisions are based on the long-term forecasts in which the demand is still unknown and must be forecast that also be referred to as speculative processes (Chopra and Meindl, 2013). The application of push strategy to giant freshwater prawn farming helps us to manage and optimise the flow of giant freshwater prawns in the supply chain network. This is because prawn farming processes respond to speculation rather than actual demand. There are a few large farming companies in Thailand that operate the complete giant freshwater prawn supply chain, they continue to use traditional techniques.

In this paper, we propose a push strategy optimization model for a marine shrimp farming supply chain network in Thailand. With the help of a mixed-integer linear programming (MILP), the proposed model explicitly considers capacity constraints, the number of truck trips for transportation and operation sequences in the marine shrimp farming network. This

model is solved to maximize the profit, which is the net revenue from giant freshwater prawn selling prices and the annual total costs, including transportation, inventory and operations cost.

The remainder of this paper is organized in the following manner. The next section provides a review of related work. Section 3 describes the model of a giant freshwater prawn supply chain network. Section 4 presents the push strategy optimization model. In section 5, we describe the solution method and present computational results using data from a real-life case study in Thailand. Finally, section 6 presents the conclusion and future work.

## 2 Related work

The supply chain network has been applied to agriculture food supply chain management for the last 10 years. Ahumada and Vilalobos (2009), for example, proposed planning models in the agriculture food supply chain. Thus, a key concern in the agriculture food supply chain is the short shelf life of perishable and seasonal products, for which substantial effort is required to maintain product freshness and shelf availability. Bilgen and Ozkarahan (2007) also studied a blending and shipping problem faced by a company dealing with a wheat supply chain. The objective function focuses on minimizing the total cost required for blending, loading, and keeping an inventory cost. Amorim et al. (2012) applied a supply chain network to the remaining shelf life of a perishable product. Mohammed and Wang (2017) developed a model for product distribution of a green meat supply chain network. Additionally, Wladimir et al. (2017) proposed the three-echelon: from farm to warehouses to processing plant in a large Chilean apple supply chain network. The network focuses on purchasing, transporting and storing fresh apples.

Our supply chain network strategies focus on push strategies. Simchi et al. (2003) identified the push strategy and production decisions as long term forecasts, whereas in push-based systems production is driven by anticipation of customer orders. A few studies were done on the agriculture food supply chain comparing it with other industries. Minnich and Maier (2007) studied the responsiveness and efficiency of push strategies, comparing them with the pull-based planning systems in the high-tech electronics industry. However, neither push strategies nor independent strategies make difference to the organizational competences due to their advantages for serving customers better and at a relatively lower cost (Dagne et al., 2014).

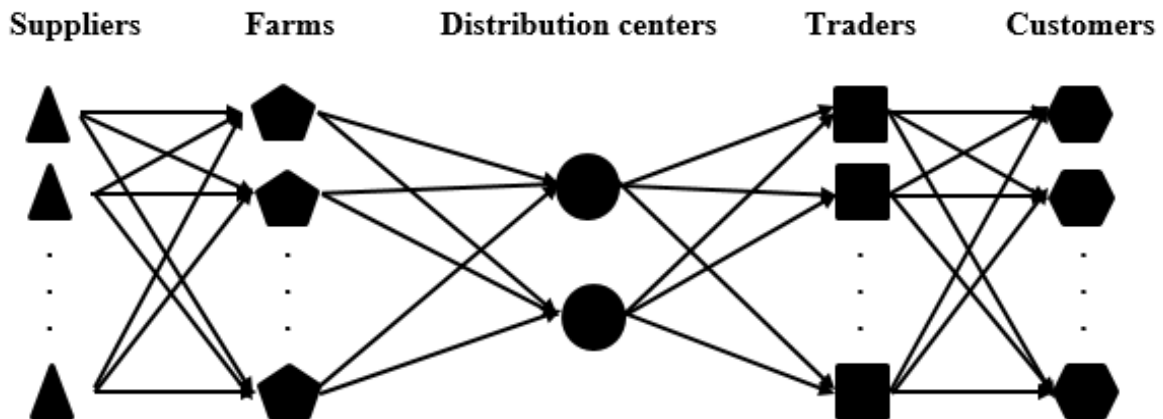
Recently, many studies on operations research (OR) models were applied to agriculture food supply chain management with sugar cane, fresh fruit, mushrooms, etc. The food supply chain is characterized by long supply lead times. These challenges generate a need for management efficiency and modern decision technology tools (Wladimir et al., 2016). For example, Zhang and Wilhelm (2011) demonstrated an interesting revision of OR models in many such crops as fruits, vegetables, tree nuts, and dried fruits. Sanjay and Marcus (2013) presented a mixed-integer linear programming model for solving problems in the sugar cane industry in Brazil. Srimanee and Routray (2012) formulated a fruits supply chain in Thailand as a network of five different supply chains linking the stages from producer to the final consumer. In addition, Chaimongkol (2015; 2017) designed a mixed-integer linear programming model for the tangerine supply chain in the northern region and aromatic coconut supply chain in Thailand. This model provided a system to integrate harvest scheduling and the production planning. OR was also used by Aleksander et al. (2017) for re-designing the structure of an industrial mushroom supply chain network. They presented a mixed integer linear programming model for decision making of the closing loops in mushroom production. Additionally, more studies were carried out focusing on the management by OR methods of fisheries and aquaculture. Understanding and managing fisheries is a very complex problem. This complexity is mainly due to the required sustainability of the underlying natural system. Nevertheless, after more than 40 years of applying OR models to the management of fisheries, it will be sensible for us to review the most successful cases in order to evaluate past performance, highlight current problems, and find future directions of research (Trond et al., 2004). Forsberg (1996) presented a production planning problem to determine the optimal number of fry for a grow-out system in fish farming. Larkin and Sylvia (1999) developed an optimal timing for the harvest for fish quality and estimated the intrinsic quality so as to determine the optimal management plan. Mistiaen and Strand (1999) formulated an optimality-conditions model for feeding rates and time of harvest in Greece when the output price is piecewise linear in weight.

According to our literature review, it has been shown that the OR models and supply chain network strategies were developed for the agricultural product supply chain. However, there is no study on the push strategy optimization methods for the marine shrimp farming management that includes the whole marine shrimp supply chain network. Although the farming has operated for more than a century, the farmers still not has support tools for developing their operation by optimizing material flow in the supply chain (Fisheries and Aquaculture Department, 2017). This paper aims to fill this gap in the literature by using a mixed-integer linear programming (MILP) model to determine a suitable operational marine shrimp farming that will maximize the profit and will improve suppliers selecting from whom to purchase the fry, prawn-feeds and supplement-feed to minimize costs for purchasing, producer administration, and prawn transportation modes. The model has been developed for improving the giant freshwater prawn supply chain in Thailand. However, this model can be used for any kind of marine shrimp supply chains that have to consider their suppliers and transportation modes selecting. The model is used in an actual case study involving the operation of giant freshwater prawn farming located in the Western region, Thailand.

### 3 Problem description

In this section, the problem of a real supply chain network of giant freshwater prawn is introduced. There are multiple echelons in the supply chain network consisting of multiple suppliers (hatchery dealers, prawn feed vendors and supplement feed suppliers), several cultivated areas, several intermediate distribution centres, several traders, several customers and several time periods. The general network structure of the supply chain network for giant freshwater prawn in the case study is presented in Figure 1.

**Figure 1** Supply chain network configuration of giant freshwater prawns in the case study



#### 3.1 Suppliers

Suppliers in the giant freshwater prawn supply chain fall into four categories. The first category are the dealers of the fry hatchery, who are divided into two groups: (1) the direct fry hatchery dealers: a farmer buys directly from the fry hatchery dealers. Each dealer has a different cost, location, and quality of fry. The farmers who decide to purchase the fry from these dealers have to buy and transport the fry to their farms by themselves, (2) the merchant middlemen: a farmer buys from a merchant middlemen, who prepares the amount of fry that farmers need and ships it directly to the farmer.

The second category are the prawn-feed vendors. There are five types of a prawn feed used for giant freshwater prawn aquaculture. Each type is used in a different time of the year and its cost varies according to the vendor.

The third and the fourth categories are the supplement-feed vendors, and the chemical suppliers for water treatment, respectively. The variety of prices and of selections offered by many vendors usually results in farmers making a wrong decision.

#### 3.2 Giant freshwater farms

Prawn farming in the area where the case study was carried out has been producing giant freshwater prawns in the West region for more than 25 years and is the one of the largest farms in Thailand. The farm covers more than 30 acres which include 6 prawn ponds for the grow-out system.

#### 3.3 Distribution centres

After harvesting market-size giant freshwater prawns from each pond, the total volume is transported to the farm's distribution centres by a truck that has a tank of plastic, fiber or canvas with aeration. The temperature of the water can be lowered by means of ice in floating plastic bags that can be transported for 5-6 hours without heavy mortality. It is essential for the farm to have a distribution centre for collecting the prawns, which are transported from various locations before being delivered to customers.

The distribution centres of the farm, located in the Central region are the Makhachai Seafood Market in Samut Sakhon Province and Talaad Thai in Pathum Thani Province. In each locality the prawns are distributed to each trader before being shipped to the customers by small trucks with aeration.

### 3.4 Traders

The farm has regular traders who deliver the prawns to each customers. Each trader distributes the volume of prawn to customers nationwide.

### 3.5 Customers

Generally, customers are seafood sellers in local markets and restaurants. These customers receive the prawns from traders.

## 4 Mathematical model

In order to present a mathematical model of the case study, the nomenclatures, and the assumptions required for the model are introduced prior to the mathematical formulation.

### 4.1 Nomenclatures

Let  $I$  be the set of hatchery dealers, with subsets for direct dealers and without delivery service ( $I_D$ ), and for merchant middlemen, with delivery service ( $I_{DM}$ ).  $P$  is the set of prawn ponds.  $V$  is the ordered set of prawn feed vendors who are chosen by the farmers during the cultivating period.  $F$  is the set of prawn-feed types.  $S$  is the set of supplement-feed suppliers.  $J$  is the set of distribution centres.  $K$  is the set of transportation methods for prawn shipping from farm to distribution centres.  $T$  is the set of cultivating and harvesting times on the time period horizon. The notations, including indices, parameters and decision variables, are as follows:

#### 4.1.1. Indices

$f$	index used for a type of prawn feed
$i$	index used for the potential of a hatchery dealer to be chosen by a farmer
$j$	index used for the potential of a distribution centre to be chosen by a farmer
$k$	index used for the potential of a method to be chosen for prawn transportation to each distribution centre
$p$	index used for the potential of a prawn pond
$s$	index used for the potential of a supplement-feed suppliers to be chosen by a farmer
$t$	index used for the cultivating and harvesting period of prawns
$v$	index used for the potential of a feed vendor to be chosen by a farmer

#### 4.1.2. Parameters

$CapD_j$	total storage capacity available in distribution centre $j$
$CapF_f$	required amount of prawn feed of type $f$ per pond
$CapFT$	shipping capacity of prawn feed per trip
$CapFV_{fv}$	selling capacity of prawn feed of type $f$ by vendor $v$
$CapGT_k$	shipping capacity of prawn per trip with transportation method $k$
$CapHT$	shipping capacity of fry per trip
$CapH_i$	purchasing capacity of fry of each hatchery dealer $i$ , $i \in I_D \cup I_{DM}$
$CapP_p$	required amount of fry for pond $p$
$CapS$	required amount of supplement feed per pond
$CapSP_s$	selling capacity of supplement feed by supplier $s$
$CapST$	maximum supplement feed shipping capacity per trip
$CapT_j$	shipping capacity of prawn for distribution centre $j$
$CosDC_j$	cost of management in each distribution centre $j$
$CosFV_{fv}$	cost of prawn feed of type $f$ by vendor $v$

$CosFT_v$	unit transportation cost from prawn feed vendor $v$
$CosH_i$	cost of young prawns which are purchased from hatchery dealer $i$ , $i \in I_D \cup I_{DM}$
$CosHT_i$	unit transportation cost from hatchery dealer $i$ , $i \in I_D$
$CosIN$	unit inventory cost
$CosLB$	cost of labour
$CosOP$	cost of pond preparation and routine pond management
$CosPT_{kj}$	unit transportation cost from farm to distribution $j$ by transportation method $k$
$CosSP_s$	cost of supplement-feed bought from each supplier $s$
$CosST_s$	unit transportation cost from supplement feed supplier $s$
$RoG^t$	growth rate of the giant freshwater prawn cultivated in time period $t$
$RoL_p$	number of labourers for harvesting in pond $p$
$SeP^t$	prawn selling prices in time period $t$

#### 4.1.3. Decision variables

$Cus^t$	total quantity of prawn delivery to customers in time period $t$
$Fed_{fv}^t$	quantity of prawn feed of type $f$ purchased from feed vendor $v$ in time period $t$
$God_j^t$	quantity of giant freshwater prawns which are harvested in time period $t$ and are transported to distribution centre $j$
$Hat_i^t$	quantity of fry purchased from hatchery dealer $i$ in time period $t$ , $i \in I_D \cup I_{DM}$
$Inv_j^t$	quantity of giant freshwater prawns stored in distribution centre $j$ at the end of period $t$
$Lab^t$	total number of labours working in time period $t$
$NFT_v^t$	number of truck trips for prawn feed shipping from vendor $v$ in time period $t$
$NGT_{kj}^t$	number of truck trips for prawn shipping to distribution centre $j$ with transportation method $k$ in time period $t$
$NHT_i^t$	number of truck trips for fry shipping from dealer $i$ in time period $t$ , $i \in I_D$
$NST_s^t$	number of truck trips for supplement feed shipping from supplier $s$ in time period $t$
$Slp_s^t$	quantity of supplement feed purchased from supplier $s$ in time period $t$
$Trd_j^t$	quantity of giant freshwater prawns which are delivered from the distribution centre $j$
$DC_j$	binary variable with value 1 if distribution centre $j$ is established, 0 otherwise
$Pon_p^t$	binary variable with value 1 if pond $p$ is used for cultivating in time period $t$ , 0 otherwise

## 4.2 Mathematical formulation

In this paper, we apply the push strategy model of the giant freshwater prawn farming in Thailand focusing on the whole supply chain network. One of the most important goals of the supply chain network is farmer and customer satisfaction of product fulfillment. According to the assumptions and the objectives, the mathematical model of the problem is a mixed-integer linear programming as follows.

### 4.2.1 Objective function

The objective function under the push strategy framework is to maximize the profit associated with the net revenue from the giant freshwater prawn selling prices, and the annual total costs, which can be expressed as:

$$\text{Max. Profit } z = \text{Net revenue} - \text{Annual total costs}$$

The first component is the net revenue that is calculated as the total revenue from the monthly sales of the giant freshwater prawns. Let  $SeP^t$  be the selling prices of the prawns in each month. The total revenue can be calculated as:

$$Net\ revenue = \sum_{j \in J} \sum_{t \in T} God_j^t \cdot SeP^t \quad (1)$$

The second component is the annual total cost, which is calculated from the cost for operation (the routine pond management and the fixed cost of management at the distribution centres), the fry hatchery purchasing cost, the prawn feed purchasing cost, the supplement-feed purchasing cost, the labour cost, the inventory cost, and the transportation cost. The total cost can be determined as:

$$\begin{aligned} Annual\ total\ costs = & \sum_{p \in P} \sum_{t \in T} Pon_p^t \cdot CosOP + \sum_{j \in J} \sum_{t \in T} DC_j^t \cdot CosDC_j \\ & + \sum_{i \in I_D \cup I_{DM}} \sum_{t \in T} Hat_i^t \cdot CosH_i + \sum_{f \in F} \sum_{v \in V} \sum_{t \in T} Fed_{fv}^t \cdot CosFV_{fv} \\ & + \sum_{s \in S} \sum_{t \in T} Slp_s^t \cdot CosSP_s + \sum_{t \in T} Lab^t \cdot CosLB + \sum_{t \in T} Inv^t \cdot CosIN \\ & + \sum_{i \in I_D} \sum_{t \in T} NHT_i^t \cdot CosHT_i + \sum_{v \in V} \sum_{t \in T} NFT_v^t \cdot CosFT_v \\ & + \sum_{s \in S} \sum_{t \in T} NST_s^t \cdot CosST_s + \sum_{k \in K} \sum_{j \in J} \sum_{t \in T} NGT_{kj}^t \cdot CosPT_{kj} \end{aligned} \quad (2)$$

#### 4.2.2 Model limitations

The model limitations for cultivating in different ponds can be calculated using constraints (3) – (6) as follows:

$$\sum_{t \in T} Pon_p^t \leq 4, \forall p \in P \quad (3)$$

Constraint (3) specifies that each pond can be cultivated exactly four times during the planning period.

Constraint (4) ensures that the farmer has a continuous product during the high harvest period. Each pond has to be cultivated at least once during the cultivating period.

$$\sum_{p \in P} Pon_p^t \geq 1, t = 1, \dots, 10 \quad (4)$$

In Thailand, farmers avoid cultivating the giant freshwater prawns in the winter season because the young prawns will stop growing in cold water. The constraint in this case is shown as constraint (5):

$$\sum_{p \in P} Pon_p^t = 0, t = 11, \dots, 13 \quad (5)$$

Normally, giant freshwater prawns can be harvested partially after three months of cultivating, when the pond  $p$  is used for cultivating in time period  $t$ . So, the farmer cannot use this pond until after the harvesting period. These limitations are described by constraint (6):

$$Pon_p^t + Pon_p^{t+1} + Pon_p^{t+2} \leq 1, \forall p \in P, t = 1, \dots, 10 \quad (6)$$

The total volume of the fry that the farmers need to purchase and the number of truck trips required for shipping the fry from each hatchery dealer can be formulated according to constraints (7) – (9):

$$\sum_{i \in I_D \cup I_{DM}} Hat_i^t \geq \sum_{p \in P} Pon_p^t \cdot CapP_p, \forall t \in T \quad (7)$$

$$Hat_i^t \leq CapH_i, \forall i \in I_D \cup I_{DM}, \forall t \in T \quad (8)$$

$$Hat_i^t \leq NHT_i^t \cdot CapHT, \forall i \in I_D, \forall t \in T \quad (9)$$

Note that a pond is fully utilized when it is selected for cultivating.

The quantity of the prawn feed that the farmer needs to purchase from the feed vendors and the number of truck trips which the farmers need to ship the prawn feed in each time period is shown by constraints (10) – (12):

$$\sum_{v \in V} Fed_{fv}^t \geq \sum_{p \in P} Pon_p^t \cdot CapF_f, \forall f \in F, \forall t \in T \quad (10)$$

$$Fed_{fv}^t \leq CapFV_{fv}, \forall f \in F, \forall v \in V, \forall t \in T \quad (11)$$

$$\sum_{f \in F} Fed_{fv}^t \leq NFT_v^t \cdot CapFT, \forall v \in V, \forall t \in T \quad (12)$$

The total quantity of the supplement-feed which the farmers need to purchase from the suppliers can be calculated using the constraints (13) - (15):

$$\sum_{s \in S} Slp_s^t \geq \sum_{p \in P} Pon_p^t \cdot CapS, \forall t \in T \quad (13)$$

$$Slp_s^t \leq CapSP_s, \forall s \in S, \forall t \in T \quad (14)$$

$$Slp_s^t \leq NST_s^t \cdot CapST, \forall s \in S, \forall t \in T \quad (15)$$

The prawns can be harvested after 3 months of culture. The model explicitly assumes that the prawns can be grown up into market-size class, and harvested completely at one time. The quantity of giant freshwater prawns harvested in each time period and the amount of labourer used for harvesting are shown in constraints (16) and (17):

$$\sum_{p \in P} Pon_p^t \cdot CapP_p \cdot RoG^t = \sum_{j \in J} God_j^{t+3}, t = 1, \dots, 10 \quad (16)$$

$$Lab^t \geq \sum_{p \in P} Pon_p^t \cdot RoL_p, \forall t \in T \quad (17)$$

The total quantity of the prawn that is transported to each distribution centre and the number of truck trips for prawn transportation to each distribution centre can be formulated with (18) and (19):

$$God_j^t \leq CapD_j \cdot DC_j, \forall j \in J, \forall t \in T \quad (18)$$

$$God_j^t \leq \sum_{k \in K} NGT_{kj}^t \cdot CapGT_k, \forall j \in J, \forall t \in T \quad (19)$$

Once prawns are transported to each distribution centre, each trader delivers them immediately to customers. Constraint (20) is the inventory balance equation representing the end-product inventory at the potential distribution centre:

$$Inv_j^t = Inv_j^{t-1} + God_j^t - Trd_j^t, \forall j \in J, \forall t \in T \quad (20)$$

Finally, the volume of the giant freshwater prawns delivered from each distribution centre to all customers by all traders is provided in constraints (21) and (22):

$$Trd_j^t \leq CapT_j, \forall j \in J, \forall t \in T \quad (21)$$

$$\sum_{j \in J} Trd_j^t = Cus^t, \forall t \in T \quad (22)$$

## 5 Computational results

The computational experiments were carried out on a personal computer with an Intel CORE i5, 8 GB of RAM and 256 GB SSD. The optimization software used for applying the proposed model to the case study is the GAMS software with CPLEX.

### 5.1 Basic case study

We first focused on a basic case study using actual data, which were provided by a specific farmer in Thailand. In the basic case study, the computational results provided the 889 decision variables and 4,519 constraints, which were generated within a computational period of 0.20 seconds after 871 iterations.

We first observed that the optimal profit in Thai Baht (THB) became 826,734, which is a 7.57% increase over the actual profit. The increase in the total profit is a result of the model's allowing minimization of the total costs of operation, fry, prawn-feed, supplement-feed, labour, inventory and transportation, as well as optimization of the best combination of the time-revenue-cost.

Furthermore, the contribution of the objective function of the model regarding total revenue and costs for each term was as follows: the total revenue in THB was 7,268,963; the total cost was divided into the cost of prawn feed purchasing for THB: 4,142,600 (64.30% of total cost); the cost of fry purchasing for THB: 686,400 (10.65%); the cost of supplement feed for THB: 632,000 (9.81%); the operation cost for THB: 524,080 (8.14%); the distribution centre management cost for THB: 300,000 (4.66%); the labour cost for THB: 120,000 (1.86%) and, finally, the cost of transportation cost for THB: 37,149 (0.58%), respectively.

Since giant freshwater prawn farming is still traditional in Thailand, the proposed model based on the push strategy will help the farmers improve their supply chain, which can increase the total profit 7.57%. This strategy is used to formulate the effective anticipation of customer orders. The cultivating, and harvesting are planned for serving customers better, and prawns are distributed to all customers at a relative with lower cost.

### 5.2 Sensitivity analysis

In order to investigate the effect of different parameters on the model of this study, a sensitivity analysis considering various variations in the area of the parameters of the proposed model was conducted (Yousefi et al., 2017).

To demonstrate the sensitivity of the basic case study model to different operating conditions, the costs of operation, raw materials, including a fry hatchery, prawn-feed, supplement-feed, labour, inventory, distribution centre management and transportation were increments of 10% in order to detect their effects on the total profit (Bligen and Ozkarahan, 2007). The result of the objective function, and the percentage differences of each cost are shown in Table 1. Inventory, and labour costs are not shown here, as they were quite small in comparison to the others.

**Table 1** Sensitivity analysis in terms of total cost increase.

Percentage change	Increasing operation cost		Increasing fry purchasing cost	
	Solution	Change in profit (%)	Solution	Change in profit (%)
10	695,326.00	15.89	691,704.00	16.33



20	635,916.00	23.08	689,518.00	16.60
30	576,308.00	30.29	620,212.00	24.98
40	511,984.00	38.07	550,765.00	33.38
50	459,919.00	44.37	467,049.00	43.51
<i>Percentage change</i>	<i>Increasing prawn feed cost</i>		<i>Increasing supplement feed cost</i>	
	<i>Solution</i>	<i>Change in profit (%)</i>	<i>Solution</i>	<i>Change in profit (%)</i>
10	421,928.00	48.96	763,734.00	7.62
20	73,022.00	91.17	700,732.00	15.24
30	-268,991.00	132.54	637,134.00	22.93
40	-545,869.00	166.03	574,183.00	30.55
50	-960,655.00	216.20	496,502.00	39.94
<i>Percentage change</i>	<i>Increasing distribution centre cost</i>		<i>Increasing transportation cost</i>	
	<i>Solution</i>	<i>Change in profit (%)</i>	<i>Solution</i>	<i>Change in profit (%)</i>
10	736,404.00	10.93	806,445.00	2.45
20	731,825.00	11.48	765,049.00	7.46
30	674,897.00	18.37	764,547.00	7.52
40	669,995.00	18.96	762,830.00	7.73
50	616,138.00	25.47	760,627.00	7.99

From Table 1, it can be seen that the total profit was sensitive to changes in cost of the prawn-feed, fry purchasing and supplement-feed. On the other hand, the transportation cost had less effect on the total profit. A 10% increase in transportation cost caused a 2.45% decrease in total profit, whereas a 10% increase in prawn feed cost caused a 48.96% decrease in total profit. The results from the model seem reasonable. The prawn feed cost influenced total profit more than the transportation cost did. Prawn-feed cost is an important cost component in the model's cost structure due to the many types of prawn feed are used for aquaculture and to the variations in their cost among vendors. The farmer therefore needs an efficient and optimal prawn feed purchasing plan for budget savings.

### 5.3 Practical case study

In addition to the basic case study in section 5.1, we considered three scenarios for case studies to represent various strategic analyses for testing the robustness of the proposed model. The scenarios are summarized as follows:

- *Scenario 1 (SC1): The basic case study*
- *Scenario 2 (SC2): Increasing the capacity of distribution centre.* The capacity of the distribution centre was increased for all time periods. This scenario denoted the situation in which one distribution centre located close to the farm was introduced.
- *Scenario 3 (SC3): Closing all distribution centres.* There were two locations for the distribution centres in this problem; the giant freshwater prawns were shipped to these locations. A distribution centre's cost was approximately 4.66% of the total cost. This scenario represented a situation in which the farmer closed all distribution centres and then had all traders pick up their own products at the farm.
- *Scenario 4 (SC4): Restrictions on the labourer.* The farmers sometimes face with the problem of hiring a sufficient number of permanent labourers due to labour shortage. In such cases, the farmers have to outsource the shortfall in labourers. In SC4, we replaced the labourer constraint (17) with constraints (23) and (24)

$$Lab^t + LabC^t \geq \sum_{p \in P} Pon_p^t \cdot RoL_p, \forall t \in T \quad (23)$$

$$Lab^t \leq CapLB, \forall t \in T \quad (24)$$

Here,  $LabC^t$  is a decision variable of the number of labourers outsourced at time period  $t$  and  $CapLB$  is the maximum number of permanent labourers that can be hired by the farmer. We also modified the annual total cost in equation (2) by replacing  $Lab^t$  with  $Lab^t + LabC^t$ .

**Table 2** The results of each scenario.

Scenarios	Solution (THB)	Time (seconds)	Tolerance gap (%)
SC1	830,514	0.20	0.004
SC2	874,122	0.26	0.03
SC3	1,180,725	0.20	0.002
SC4	776,350	0.19	0.04

The results of solving the four scenarios are presented in Table 2. The solution time from all scenarios were acceptable and within practical time limits. The tolerance gap was approximately 0.002%-0.04% for the four scenarios. It can be seen that the quality of the results was very high and approached closely the optimal solution.

The solution from the SC2 showed that the capacity of distribution centre located close to the farm increased. The results were clearly different from those of the SC1, where the model used only one distribution centre in each time period. Technically, the total profit was increased to THB 874,122, an increase of approximately a 5.25. This profit increase came after the reducing cost of distribution centre management was reduced 33.33% when compared with the distribution centre management cost from the SC1.

Therefore, the result from the SC3 also showed a total profit increase of about 42.17%. Normally, the distribution centre management cost contributed 4.66% of the total cost. The scenario SC3, which is based on the traders themselves shipping the prawns from the farm. In that case, the farmers need not ship the prawns to each distribution centre, thus reducing the distribution centre management cost and the cost of transportation cost from the farm to each distribution centre.

Finally, the SC4 included a restriction that the number of workers never exceeds 35 in each time period. If it is necessary to go beyond the restriction, the farmer will need to outsource work, hiring more workers and thus increasing labour costs. This restriction can mean an increase in the labour costs of about THB 42,500, bringing a 7.92% increase, when compared to the SC1.

Nevertheless, it is hard to compare the scenarios SC2, SC3, and SC4 solutions with the actual results, since there are no manual solutions for these cases. These scenarios, however, can provide solutions to the farmers if the scenarios occur in real situations. The proposed model can produce better, and more flexible solutions to allow easy testing of different scenarios.

## 6 Conclusions

In summary, the giant freshwater prawn farming is one of forms of marine shrimp aquaculture. In Thailand, methods used are still traditional. This study develops the push strategy and the operations research method to solve the problem of supply chain network for giant freshwater prawn farming. The main purpose is to present a model and an approach that can be used as a decision support tool for supply chain network strategic analysis. The proposed mixed-integer linear programming model gave a detailed description of the supply chain network, and different scenarios were simulated for the different situations. Experiments were carried out with the model in the real cases, and a sensitivity analysis was conducted for the incremental changes from 10% to 50%. The push strategy was used for optimal solutions within a small tolerance gap of the different scenarios over the planning horizon. The proposed model can generate better and more flexible solutions than actual planning by the farmer, and allow easy testing of the different scenarios and strategies. Finally, possible future research is the development of a multi-objective for the supplier reliability in the network, since suppliers may not always operate perfectly, given the inevitable natural disasters and inclement weather.

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