PRIMARY RESEARCH

Pareto-based algorithm for adaptive aggregate production and distribution planning in shrimp agroindustry supply chain

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Abstract
In the global supply chain, the integration of production and distribution is one of the important activities that must be carried out. This also applies to the shrimp agroindustry supply chain. The shrimp agroindustry is one of the agro-food industries that deals with processing raw shrimp into various frozen shrimp products. The demand for frozen shrimp products is very diverse, while the supply of raw shrimp consists of various sizes and has perishable properties. To fulfill consumer demand, aggregate production planning must be made adaptively. Adaptive means being able to improve aggregate planning due to changes in demand. Integration of adaptive aggregate production and distribution planning will result in better planning. Based on this, we developed an adaptive aggregate production and distribution model for the shrimp agroindustry supply chain. Non-dominated Sorting Genetic Algorithm II (NSGA-II) which is a pareto-based algorithm is used to solve the problem. The aim is to minimize total costs and maximize service levels. The sample problem from the shrimp agroindustry in East Java is used to show the efficiency of the proposed algorithm.

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I. INTRODUCTION

The shrimp agroindustry is one of the agro-food industries that deals with processing raw shrimp into various frozen shrimp products. In Indonesia, the shrimp agroindustry is an agroindustry in the fisheries sector that has strong competitiveness. According to [1] product and service quality, customer satisfaction, and the low cost of production and distribution are factors that affect the competitiveness of a company. In order to achieve this, collaboration between actors in the supply chain is inevitable.

One form of collaboration is to integrate production and distribution planning activities. As known, production planning plays an important role in the production system, because it can manage all production activities in an industry. One of the activities in production planning is Aggregate Production Planning (APP).

APP is medium-term planning that aims to make a strategy to determine amount of production, inventory and workforce level in order to meet fluctuating demand [2, 3, 4]. APP is also important for shrimp agroindustry to determine optimal production planning with capacity availability. This is becoming increasingly important, because shrimp agroindustry is the same as other food production which has special characteristics, such as seasonal, perishable product, diverse yields, and fluctuating demand [5, 6].

The demand for frozen shrimp products varies in each period and depends on the sizes of the shrimp. On holi days, demand will be very high and then decrease afterwards. Majority consumers tend to order small size shrimp products, while others order medium or large sizes. According to irregular demand, production planning must always be updated. In other words, it is necessary for shrimp agroindustry to run an Adaptive Aggregate Production Planning...
III. SHRIMP AGROINDUSTRY PRODUCTION

This section describes a shrimp agroindustry production. Production activities in the shrimp agroindustry start from receiving raw materials to stuffing, which is the process of loading products into containers before shipping. Shrimp agroindustry produced frozen shrimp products. Each product freezing process can be done individually quick freezing (IQF) and semi IQF. The production process in shrimp agroindustry is illustrated through a product transformation (Figure 1) [23].

The raw material for the product is raw shrimp that perishable and various sizes. Intermediate products function as shrimp raw materials in the form of blocks frozen. Blocks frozen are produced after peeling and deveining. It can be stored between 3-6 months in cold storage. The final product is processed frozen shrimp, consists of various sizes according to consumer demand. It can be stored in cold storage no
more than 6 months. Production activities on the shop floor are carried out manually and automatically. Manual processes include receiving raw material, washing, shrimp head cutting, sorting and grading, and also peeling and deveining. After that, the processes are done automatically. When the production process is complete, the final product is stored in cold storage before being distributed to buyers. Limited storage space, making the product distribution process must be planned carefully. This plan is made so that production activities are balanced with distribution activities.

The shrimp agroindustry is full of uncertainties including shrimp size and demand patterns, which makes decision making more complex. Decisions about how much to produce several products must be made clearly. It is hard because the production planners must optimize resources and adjust production to uncertain demands, so that it can eventually compete with similar businesses. The effect of uncertainty on the shrimp agroindustry and its implications for integrated aggregate production and distribution planning will be assessed qualitatively in this study.

Fig. 1. Product transformation in shrimp agroindustry

IV. PROBLEM DESCRIPTION AND MODEL FORMULATION

A. Problem Description

Shrimp agroindustry supply chain in this study consists of suppliers, shrimp agroindustry, logistics provider companies, and buyers. The aim is to minimize total costs as well as maximize service levels. At the production stage, there are unique characteristics in the system: perishable raw materials, yield differences in each shrimp size, final product demand which varies depending on the type of product group and shrimp size.

The shrimp agroindustry receives raw materials in the form of raw shrimp from three suppliers group. Groups of suppliers consist of suppliers of fish auctions, intensive pond suppliers, and traditional pond suppliers. Raw materials are transported from suppliers to shrimp agroindustry using insulated trucks. When distributing, it is possible to have the raw material damage. This causes a reduction in the number of shrimps that can be accepted by agroindustry.

The shrimp agroindustry produces two types of frozen shrimp products, namely frozen raw shrimps and frozen cooked shrimps. Frozen shrimp products and block frozen can be produced in regular and overtime production. When demand for frozen shrimp products increases, shrimp agroindustry can hire workers and vice versa when demand decreases, labor can be laid off. Frozen shrimp products are transported by logistics service companies to buyers.

B. Model Formulation

Multi-objective model is delivered to contribute to integrated adaptive aggregate production and distribution planning in shrimp agroindustry supply chain. The objectives include minimize total cost and maximize customer satisfaction. The notations for mathematical model are as follows:

Index:
- $s$ index of shrimp size, $s \in S$.
- $i$ index of supplier groups of fish auctions, $i \in I$.
- $j$ index of intensive farm supplier groups, $j \in J$.
- $k$ index of traditional farm supplier group, $k \in K$.
- $l$ index of logistics provider company, $l \in L$.
- $b$ index of the buyer, $b \in B$. 
c index of frozen shrimp products, $c \in C$ (1 = frozen cooked shrimp product group, 2 = group of frozen raw shrimp products).

t Index time, $t \in T$.

Notations:

- A notation for shrimp agroindustry.
- LS notation for a logistics provider company.
- $B$ notation for buyers.
- $D$ notation for demand.
- $BF$ notation for block is frozen.
- $P$ notation for the purchase price of raw materials.
- $N$ notation for capacity.
- $CP$ notation for production costs.
- $CI$ notation for inventory costs.
- $CL$ notation for labor costs.
- $l0$ notation for initial inventory.
- $\theta$ notation for the percentage of damage to the transportation process.
- $\zeta$ notation for the percentage level of use of raw materials.

Parameters:

- $\check{D}_{cs}$ fuzzy demand for frozen shrimp product $c$ with size $s$ in period $t$
- $P_{is}$ price per kilogram of shrimp with size $s$ from the supplier of fish auction $i$.
- $P_{js}$ price per kilogram of shrimp with size $s$ from intensive pond suppliers $j$.
- $P_{ks}$ price per kilogram of shrimp with size $s$ from traditional pond suppliers $k$.
- $N_c$ production machine capacity for frozen shrimp products $c$.
- $NBF$ production machine capacity for the block is frozen.
- $N_l$ capacity of vehicles transporting processed shrimp products logistics service companies $l$.
- $N_{cs}$ shrimp supplier capacity.
- $CP_{cs}$ cost of producing frozen shrimp product $c$ with size $s$.
- $CPBF_{cs}$ cost of producing of block frozen with size $s$.
- $CPBF_{Xcs}$ cost of block frozen production into frozen shrimp product $c$ with size $S$.
- $CW_{cs}$ cost of shortage for frozen shrimp product $c$ with size $s$ in period $t$.
- $CIBF_{cs}$ inventory cost block frozen with size $s$.
- $CIT_{cs}$ inventory cost frozen shrimp product $c$ with size $s$.
- $IOBF_{i}$ initial inventory block frozen with size $s$.
- $IO_{cs}$ initial inventory frozen shrimp product $c$ with size $s$.
- $\theta_i$ percentage of shrimp damage during transportation from supplier of fish auction $i$ to agroindustry.
- $\theta_j$ percentage of shrimp damage during transportation from intensive pond suppliers $j$ to agroindustry.
- $\theta_k$ percentage of shrimp damage during transportation from traditional pond suppliers $k$ to agroindustry.
- $\zeta_{BF}$ Shrimp yield for block frozen.
- $\zeta_c$ Shrimp yield for frozen shrimp product $c$.
- $P_{ic}^t$ Percentage of shrimp supply to become product $c$ in period $t$.
- $P_{iBF}^t$ Percentage of shrimp supply to become block frozen product in period.
- $CLO_{it}$ cost of one man-hour of labor on regular time in period $t$.
- $CLO_{it}$ cost of one man-hour of labor on overtime in period $t$.
- $CH_t$ cost of hiring a man-hour in period $t$.
- $CF_t$ cost of firing a man-hour in period $t$.
- $MP_{cs}^t$ Man-hour require to produce a unit of frozen shrimp product $c$ with size $s$.
- $MPBF_{cs}^t$ Man-hour require to produce a unit of block frozen with size $s$.
- $\rho$ Proportion of regular working hour that is allowed.

Variable decisions:

- $IBF_{cs}^t$ quantity of inventory block frozen with size $s$ in period $t$.
- $I_{cs}^t$ quantity of inventory frozen shrimp product $c$ with size $s$ at the end of period $t$.
- $F_{is}^t$ quantity of shrimp with size $s$ that supply from supplier of fish auction $i$ in period $t$.
- $F_{js}^t$ quantity of shrimp with size $s$ that supply from intensive pond suppliers $j$ in period $t$.
- $F_{ks}^t$ quantity of shrimp with size $s$ that supply from traditional pond suppliers $k$ in period $t$.
- $G_{ics}^t$ quantity of frozen shrimp product $c$ with size $s$ from agroindustry to logistics provider company $l$ in period $t$.
- $G_{locbs}^t$ quantity of frozen shrimp product $c$ with size $s$ from logistics provider company $l$ to buyer $b$ in period $t$.
- $Q_{cs}^t$ quantity of frozen shrimp product $c$ with size $s$ that produce in period $t$.
- $QBF_{cs}^t$ quantity of block frozen with size $s$ that produce in period $t$.
- $QBF_{cs}^t$ quantity of block frozen that produce to be frozen shrimp product $c$ with size $s$ in period $t$.
- $W_{cs}^t$ quantity of shortage frozen shrimp product $c$ with size $s$ in period $t$.
- $L_{it}$ Man-hour employed on regular time in period $t$.
- $LO_{it}$ Man-hour employed on overtime in period $t$.
- $H_t$ Number of man-hour hired in period $t$.
- $F_t$ Number of man-hour firing in period $t$.
- $X_{cs}^t$ binary variable if frozen shrimp product $c$ with size $s$ that produce in period $t$.
- $XBF_{cs}^t$ binary variable if block frozen with size $s$ that produce in period $t$. 
The proposed mathematical model for APP in shrimp agroindustry is provided as follows:

\[ Z_f = \text{Minimize total cost of supply chain} \]

\[ \sum s_i \sum c \sum t_i P_{is} F_{is}^t + \sum s_j \sum s \sum t_j P_{js} F_{js}^t + \sum k \sum s \sum t_k P_{ks} F_{ks}^t \]  

(1)

**D. Production process cost (PC)**

\[ \sum s \sum c \sum t P_{is}^t F_{is}^t XBF_{cs}^t \]

\[ + \sum s \sum s \sum s P_{is}^t XBF_{cs}^t XBF_{cs}^t \]

\[ + \sum s \sum t \sum s \sum t CP_{cs} XBF_{cs}^t \]  

(2)

**E. IC**

\[ \sum s \sum t CBF_{cs} I_{cs}^t \]

\[ + \sum s \sum s \sum t CBF_{cs} I_{cs}^t \]  

(3)

**F. DC**

\[ \sum s \sum t P_{is}^t F_{is}^t \theta_i \]

\[ + \sum s \sum t P_{js}^t F_{js}^t \theta_j \]

\[ + \sum s \sum t P_{ks}^t F_{ks}^t \theta_k \]  

(4)

**G. LC**

\[ \sum t CLR_t LR_t \]

\[ + \sum t CLO_t LO_t \]

\[ + \sum t CH_t H_t \]

\[ + \sum t CF_t F_t \]  

(5)

\[ Z_2 = \text{maksimasi customer satisfaction} \]

\[ Z_2 = \sum c \sum s \sum t \frac{D_{cs}^t - W_{cs}^t}{D_{cs}^t} \]  

(6)

Subject to: Inventory

\[ IBF_{cs}^t \]

\[ = IBF_{cs}^{t-1} + QBF_{cs}^t \]

\[ - \sum c QBF_{cs}^t \]  

(7)

\[ I_{cs}^t \]

\[ = I_{cs}^{t-1} \]

\[ + \left( \sum c Q_{cs}^t + \sum c QBF_{cs}^t \right) \]

\[ - \sum c W_{cs}^t \]  

(8)

\[ Z_1 = \text{raw material Procurement Cost (OC) + production Process Cost (PC) + Inventory Cost (IC) + Damage Cost (DC) + Labor Cost (LC)} \]

**C. Raw material OC**

\[ \sum c \sum t \sum s \sum t Q_{cs}^t + \sum c \sum t \sum s \sum t QBF_{cs}^t \leq N_{cs} \]  

(9)

Supply

\[ \sum c \sum t \sum s \sum t Q_{cs}^t + \sum c \sum t \sum s \sum t QBF_{cs}^t \leq N_{cs} \]  

(10)

Capacity

\[ \sum c \sum t \sum s \sum t Q_{cs}^t + QBF_{cs}^t \leq N_{cs} \]  

(11)

Production

\[ \sum c \sum t \sum s \sum t Q_{cs}^t + \sum c \sum t \sum s \sum t QBF_{cs}^t \leq N_{cs} \]  

(12)

\[ \sum c \sum t \sum s \sum t Q_{cs}^t + \sum c \sum t \sum s \sum t QBF_{cs}^t \leq N_{cs} \]  

(13)

\[ \sum c \sum t \sum s \sum t Q_{cs}^t + QBF_{cs}^t \leq NBF \]  

(14)

\[ \sum c \sum t \sum s \sum t Q_{cs}^t + \sum c \sum t \sum s \sum t QBF_{cs}^t \leq NBF \]  

(15)
shrimp product groups. For the research sample, Cooked Peeled Tail On (CPTO) and Peeled Deveined (PD) products used with shrimp size 51/60, 61/70, and 71/90. CPTO represents the group of frozen cooked shrimp, while PD is the frozen raw shrimp group.

Integrated adaptive aggregate production and distribution planning model is completed using pareto based algorithm, the Multi-Objective Evolutionary Algorithm (MOEA) Framework version 2.8. The program exercises in the Java programming language. NSGA-II through MOEA is applied to solve the problem. The model is run using PC with processor InterR Core™ i5-6200U CPU @ 2.30GHz 2.40 GHz, RAM 4 GB, under 64-bit Operating System.

A case study of the shrimp agroindustry supply chain examined with 20000 generations and 600 population. The algorithm parameters based on [24]. Table 1 shows the parameters in this study.

**V. COMPUTATIONAL RESULT AND DISCUSSION**

This research was conducted in Gresik, East Java, Indone-
sia. The shrimp agroindustry produces two types of frozen

$$ LR_t + LR_{t-1} - H_t + F_t = 0 $$

$$ MP_{cs}(Q_{cs}^t + QBF_{cs}^t) + MPBF_{cs}(Q_{cs}^{t-1} + QBF_{cs}^t) \leq LR_t + LO_t $$

$$ LO_t - \rho LR_t \leq 0 $$

Binary and integer

$$ I, F, G, Q, W, LR, LO, H, F \geq 0 \text{ and integer } X \in \{0, 1\} $$

**TABLE 1**

| Parameter Description | Default Value |
|-----------------------|---------------|
| Population Size with Replacement | Population size Used binary tournament selection true or false | 600 True |

Figure 2 represents the pareto front of integration adaptive aggregate production and distribution planning in shrimp agroindustry supply chain with 25,000 generations. 

Alternative decisions for the results in Figure 1, are shown in Table 2.

The best solution for alternative decisions is based on the filtering/Displaced Ideal Solution (DIS) method in [25].

Tabel 3 shown the best solution for integrated adaptive aggregate production and distribution planning in shrimp agroindustry supply chain model.
Table 2 shows the best solution for the integrated adaptive aggregate production and distribution planning in shrimp agroindustry supply chain model. The best solution is alternative decision 13th with total cost ($Z_1 = 267,938,562,000$ IDR) and service level ($Z_2 = 1,487,944.40$ kg).

### VI. CONCLUSION

In this paper we introduce integrated aggregate production and distribution planning model for shrimp agroindustry supply chain. To find pareto front, we took NSGA II. The model considers fuzzy numbers in demand for frozen shrimp product. The DIS methods was used to discover the best solution from alternative decisions. For future research, several parameters model such as cost can be extended in the fuzzy. Supplier selection can be considered in the model.

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