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PRIMARY RESEARCH

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

L. Herlina [1*], Machfud [2], E. Anggraeni [3], Sukardi [4]
[1] Faculty of Engineering, University of Sultan Ageng Tirtayasa, Banten, Indonesia
[1, 2, 3, 4] Faculty of Agricultural Technology, IPB University, Bogor Agricultural University, Bogor, Indonesia

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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.

I. INTRODUCTION

The shrimp agroindustry is one of 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

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[*] Corresponding author: L. Herlina Machfud

[†] email: lely@untirta.ac.id

(AAPP). Not only AAPP, but distribution is also a major challenge for perishable product [7, 8]. So that, integration of adaptive aggregate production and distribution planning is one of the important activities in the global supply chain.

Based on [9], the advantages of integrating production and distribution planning are maximizing profits, minimizing lead time and responding to market change quickly. Shrimp agroindustry supply chain need to do the same thing, for several reasons: many actors involved in the supply chain, perishable raw materials, and limited storage space. Another important reason for integration is the short lead time. This is in line with [10] which states that the integration of production and distribution planning needs to be done on a production system with short lead times.

This paper aims to develop an integrative adaptive aggregate production and distribution planning model for shrimp agroindustry supply chain which objective is to minimize total cost and and maximize customer service level. The integration based on fuzzy mixed integer programming considering shrimp suppliers, a shrimp agroindustry, logistics provider companies and buyers. The optimization model was solved by a NSGA-II which is a pareto-based algorithm. The rest of this study is organized as follows. Section 2 presents literature review on integration aggregate production and distribution planning. Section 3 describe shrimp agroindustry production. Section 4 deals with problem description and model formulation. Section 5 discusses the result of the model. Section 6 provide the conclusions of the study.

II. LITERATURE REVIEW

In this section, we present an overview of the literature related to aggregate production and distribution planning. A comprehensive literature review of integrated production and distribution planning organized by [9]. The study of aggregate production and distribution planning has been carried out by [11]. The fuzzy model was used to release uncertain condition with multi-objectives which maximizes profit and fill rates. Optimization model solved by genetic algorithm. Similar to [11], fuzzy models for integration of aggregate production and distribution planning are also used by [12]. This research considered suppliers, manufacturers, subcontractors, retailers, and customer to minimize total costs. Different objective functions from [11] and P [12] are used by [13] on the developed fuzzy models for integrating aggregate production and distribution planning. [13] suggested to minimize total costs and maximize the reliability of transportations products to overcome demand uncertainty. Another fuzzy model was developed by [14, 15]. They suggested an analytical model with qualitative and quantitative criteria and proposed Multi-Criteria Decision Making (MCDM) to measure performance.

[16] proposed a two-stage stochastic program to control uncertainty in the weather and demand in the fresh fruit product industry. Meanwhile, memetic algorithm is used by [17] to minimize the total cost in the automotive industry. In this study, aggregate demand is assumed to be deterministic and can be fulfilled at regular time, overtime or subcontracting. [18] considered a multi-site, multi-period, multi-product APP model in green supply chain management. Environmental criteria in the presented model not only limited by greenhouse gas emission but include recyclability, biodegradability, energy consumption and product risk that scored using Analytical Hierarchy Process (AHP). [19] present a multi objective model for a multi-product, multi-site APP in supply chain considering supplier selection. [20, 21] implemented APP model in mushroom industry. They prososed a multi-objective two-stage stochastic model to appraise the economic and environmental impact.

[22] studied tactical production and distribution planning with dependency issues on the production process. This work provided mixed integer linear programming for two stage production process on a single plant. Their goal is to calculate total cost including inventory, transportation, backlog, lost sales, and setu up.

According to literature review, the main contribution of this paper is to design integrated adaptive aggregat production and distribution planning model for shrimp agroindustry that can support as a decision makers in perishable production processes.

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 store 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 store 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.

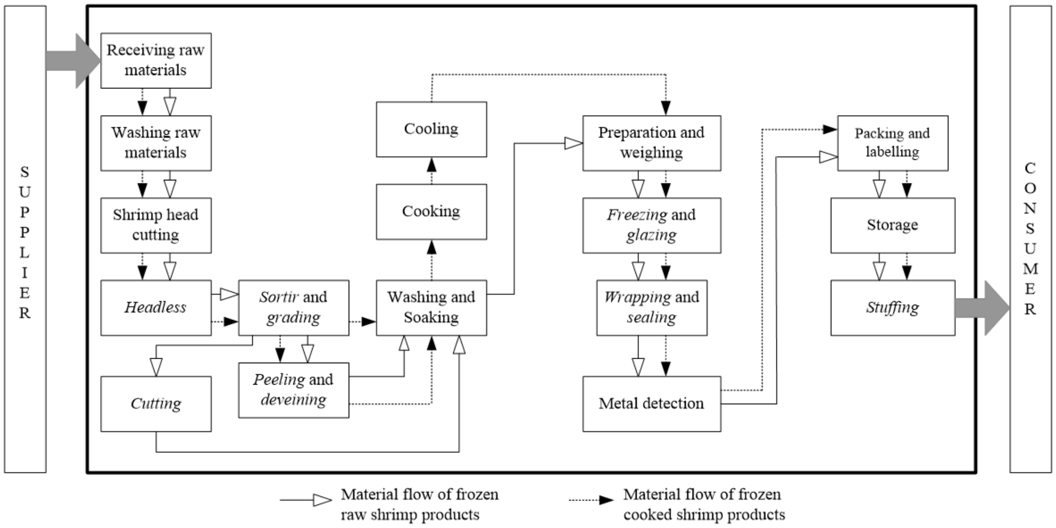

Fig. 1. Product transformation in shrimp agroindustry

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, $s \ \epsilon \ S$.
i index of supplier groups of fish auctions, $i \ \epsilon \ I$.
j index of intensive farm supplier groups, $j \ \epsilon \ J$.
k index of traditional farm supplier group, $k \ \epsilon \ K$.
l index of logistics provider company, $l \ \epsilon \ L$.
b index of the buyer, $b \ \epsilon \ B$.

c index of frozen shrimp products, $c \ \epsilon \ C$ (1 = frozen cooked shrimp product group, 2 = group of frozen raw shrimp products).

t Index time, $t \ \epsilon \ T$.

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.

I0 notation for initial inventory.

θ notation for the percentage of damage to the transportation process.

ζ notation for the percentage level of use of raw materials.

Parameters:

$\widehat{D}_{cs}^{t}$ 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_{ss} shrimp supplier capacity.

$\boldsymbol{CP}_{cs}$ cost of producing frozen shrimp product c with size s

$CPBF_s$ cost of producing of block frozen with size s

$CPBF_{cs}$ cost of block frozen production into frozen shrimp product c with size S

CW_{cs}^{t} cost of shortage for frozen shrimp product c with size s in period t

$CIBF_s$ inventory cost block frozen with size s

$\boldsymbol{CI}_{cs}$ inventory cost frozen shrimp product c with size s

$IOBF_s$ initial inventory block frozen with size s

IO_{cs} initial inventory frozen shrimp product c with size s

θ_i percentage of shrimp damage during transportation from supplier of fish auction i to agroindustry.

θ_j percentage of shrimp damage during transportation from intensive pond suppliers j to agroindustry.

θ_k percentage ofshrimp damage during transportation from traditional pond suppliers k to agroindustry.

$\boldsymbol{\zeta BF}$ Shrimp yield for block frozen

$\boldsymbol{\zeta}_c$ Shrimp yield for frozen shrimp product c

P_c^t Percentage of shrimp supply to become product c in period t

P_{BF}^t Percentage of shrimp supply to become block frozen product in period

CLR_t cost of one man-hour of labor on regular time in period t

CLO_t cost of one man-hour of labor on overtime in period t

CH_t cost of hiring a man-hour of labor in period t

$\boldsymbol{CF}_t$ cost of firing a man-hour of labor in period t

MP_{cs} Man-hour require to produce a unit of frozen shrimp product c with size s

$MPBF_s$ Man-hour require to produce a unit of block frozen with size s

$\boldsymbol{\rho}$ Proportion of regular working hour that is allowed.

Variable decisions:

IBF_s^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_{lcs}^t quantity of frozen shrimp product c with size s from agroindustry to logistic provider company l in period t

G_{lbcs}^t quantity of frozen shrimp product c with size s from logistic 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_s^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

$\boldsymbol{W}_{cs}^t$ quantity of shortage frozen shrimp product c with size s in period t

$\boldsymbol{LR_t}$ Man-hour employed on regular time in period t

$\boldsymbol{LO_t}$ Man-hour employed on overtime in period t

$\boldsymbol{H}_t$ Number of man-hour hired in period t

$\boldsymbol{F}_t$ 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_s^t binary variable if block frozen with size s that produce in period t

XBF_{cs}^{t} binary variable if block frozen change to be frozen shrimp product c with size s in period t

The proposed mathematical model for APP in shrimp agroindustry is provided as follows:

Z_I : Minimize total cost of stupply chain

Z_1 = raw material Procurement Cost $(OC)+$ production Process Cost $(PC)+$ Inventory Cost$(IC)+$ Damage Cost $(DC)+$ Labor Cost (LC)

C. Raw material OC

$$\sum_{i}\sum_{s}\sum_{t}P_{is}F_{is}^{t}+\sum_{j}\sum_{s}\sum_{t}P_{js}F_{js}^{t}+\sum_{k}\sum_{s}\sum_{t}P_{ks}F_{ks}^{t} \tag{1}$$

D. Production process cost (PC)

$$\begin{aligned}&\textstyle\sum_{s}\sum_{cPBF_{s}QBF_{s}^{t}XBF_{s}^{t}}\\&+\textstyle\sum_{S}^{t}\sum_{S}\sum_{SPBF_{cs}QBF_{cs}^{t}XBF_{cs}^{t}}\\&+\textstyle\sum_{s}\sum_{s}\sum_{t}^{s}CP_{cs}Q_{cs}^{t}X_{cs}^{t}\end{aligned} \tag{2}$$

E. IC

$$\sum_{s}\sum_{t}CIBF_{s}IBF_{s}^{t}+\sum_{c}\sum_{s}\sum_{t}CI_{s}I_{cs}^{t} \tag{3}$$

F. DC

$$\begin{aligned}&\textstyle\sum_{i}\sum_{s}\sum_{t}P_{is}F_{is}^{t}\theta_{i}\\&+\textstyle\sum_{j}\sum_{s}\sum_{t}P_{js}F_{js}^{t}\theta_{j}\\&+\textstyle\sum_{k}\sum_{s}\sum_{t}P_{ks}F_{ks}^{t}\theta_{k}\end{aligned} \tag{4}$$

G. LC

$$\begin{aligned}&\textstyle\sum_{t}CLR_{t}LR_{t}\\&+\textstyle\sum_{t}CLO_{t}LO_{t}\\&+\textstyle\sum_{t}^{t}CH_{t}H_{t}+\sum_{t}CF_{t}F_{t}\end{aligned} \tag{5}$$

$Z_2 =$ maksimasi customer satisfaction

$$Z_{2}=\sum_{c}\sum_{s}\sum_{t}\frac{\widehat{D_{cs}^{t}}-W_{cs}^{t}}{\widehat{D}_{cs}^{t}} \tag{6}$$

Subject to: Inventory

$$\begin{aligned}&\boldsymbol{IBF_{s}^{t}}\\&=IBF_{s}^{t-1}+QBF_{s}^{t}\\&-\sum_{c}\boldsymbol{QBF_{cs}^{t}},\quad\forall\boldsymbol{t}\end{aligned} \tag{7}$$

$$\begin{aligned}&I_{cs}^{t}\\&=I_{cs}^{t-1}\\&+\left(\sum_{c}\boldsymbol{Q}_{cs}^{t}+\sum_{c}\boldsymbol{Q}BF_{cs}^{t}\right)\\&-\sum_{c}W_{cs}^{t}\quad\forall s,l,t\end{aligned} \tag{8}$$

Flow

$$\begin{aligned}&\textstyle\sum_{c}G_{lbcs}^{t}\\&\leq\widehat{D}_{bcs}^{t+n}\quad\forall s,l,b,t,n\end{aligned} \tag{9}$$

$$\begin{aligned}&\sum_{c}G_{lcs}^{t}\\&\leq G_{lbcs}^{t+n}\quad\forall l,b,c,s,t\end{aligned} \tag{10}$$

$$\begin{aligned}&\sum_{c}\left(\boldsymbol{Q}_{cs}^{t}+\boldsymbol{Q}BF_{sc}^{t}\right)\\&\geq\overset{+}{\sum_{c}}c_{cs}^{\ t}G_{lcs}^{t}\quad\forall s,l,t\end{aligned} \tag{11}$$

Supply

$$\begin{aligned}&\textstyle\sum_{i}F_{is}^{t}+\sum_{i}F_{js}^{t}+\sum_{k}F_{ks}^{t}\\&\leq N_{ss}\end{aligned} \tag{12}$$

Capacity

$$\begin{aligned}&\boldsymbol{Q_{cs}^{t}}+\boldsymbol{QBF_{cs}^{t}}\\&\leq N_{c}\quad\forall\boldsymbol{s},\boldsymbol{t},\boldsymbol{c}\end{aligned} \tag{13}$$

$$\begin{aligned}&\textstyle\sum_{s}QBF_{s}^{t}\\&\leq NBF\quad\forall t\end{aligned} \tag{14}$$

$$\begin{aligned}&\textstyle\sum_{c}\sum_{s}\boldsymbol{G}_{\mathrm{lbcs}}^{t}\\&\leq N_{l}\qquad\qquad\forall l,s,t\end{aligned} \tag{15}$$

Production

$$\begin{aligned}&\textstyle\sum_{c}\boldsymbol{Q}_{cs}^{t}\boldsymbol{X}_{cs}^{t}+\sum_{c}\boldsymbol{QBF}_{cs}^{t}\boldsymbol{XBF}_{cs}^{t}\\&\leq\textstyle\sum_{i}\left(\boldsymbol{P}_{c}^{t}\boldsymbol{F}_{is}^{t}\right)\zeta_{cs}\\&+\textstyle\sum_{j}\left(\boldsymbol{P}_{c}^{t}\boldsymbol{F}_{js}^{t}\right)\boldsymbol{z}_{cs}\\&+\textstyle\sum_{\boldsymbol{k}}\left(\boldsymbol{P}_{c}^{t}\boldsymbol{F}_{ks}^{t}\right)\zeta_{cs}\quad\forall\boldsymbol{i},\boldsymbol{j},\boldsymbol{k},\boldsymbol{s},\boldsymbol{t}\end{aligned} \tag{16}$$

$$\begin{aligned}&\boldsymbol{QBF}_{s}^{t}\\&=\left(\boldsymbol{P}_{BF}^{t}\boldsymbol{F}_{is}^{t}\right)\boldsymbol{BF}_{s}\\&+\left(\boldsymbol{P_{BF}^{t}F_{js}^{t}}\right)\boldsymbol{BF_{s}}\\&+\left(\boldsymbol{P_{BF}^{t}F_{ks}^{t}}\right)\zeta\boldsymbol{BF_{s}}\quad\forall\boldsymbol{i},\boldsymbol{j},\boldsymbol{k},\boldsymbol{s},\boldsymbol{t}\end{aligned} \tag{17}$$

Labor

$$\boldsymbol{LR}_t + \boldsymbol{LR}_{t-1} - H_t + F_t = 0 \tag{18}$$

$$\boldsymbol{MP}_{cs}\left(\boldsymbol{Q}^t_{cs} + \boldsymbol{QBF}^t_{cs}\right) + MPBF_s\left(Q^t_{cs} + \boldsymbol{QBF}^t_{cs}\right) \leq LR_t + LO_t \tag{19}$$

$$\boldsymbol{LO}_t - \boldsymbol{\rho LR}_t \leq \boldsymbol{0} \tag{20}$$

Binary and integer

$$\boldsymbol{I}, \boldsymbol{F}, \boldsymbol{G}, \boldsymbol{Q}, \boldsymbol{W}, \boldsymbol{LR}, \boldsymbol{LO}, \boldsymbol{H}, \boldsymbol{F} \geq \boldsymbol{0} \text{ and integer} X \in \{0, 1\} \tag{21}$$

V. COMPUTATIONAL RESULT AND DISCUSSION

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

TABLE 1
PARAMETERS MODEL

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.

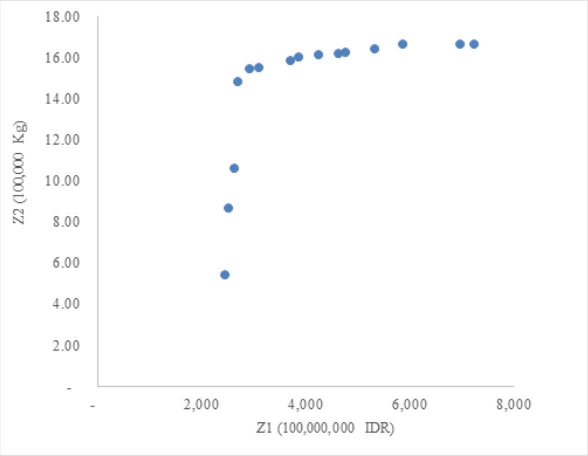

Fig. 2. Pareto front with 25,000 generations

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
ALTERNATIVE DECISIONS BASED ON NSGA-II

Alternative	Total cost Z_1 (IDR)	Service level Z_2 (Kg)
1	244,302,660,000	546,078.70
2	585,887,840,000	1,668,097.20
3	696,091,150,000	1,668,201.40
4	530,853,560,000	1,647,855.80
5	309,109,916,000	1,557,448.80
6	422,520,521,000	1,617,602.00
7	723,201,360,000	1,671,013.90
8	369,105,076,000	1,587,422.60
9	475,413,938,000	1,628,713.50
10	384,336,724,000	1,609,001.10
11	461,892,289,000	1,625,790.00
12	290,295,218,000	1,551,694.80
13	267,938,562,000	1,487,944.40
14	251,370,881,000	873,756.80
15	262,044,123,000	1,067,612.40

TABLE 3
THE BEST SOLUTION USING DIS METHOD

Alternative	Total cost Z_1 (IDR)	Service level Z_2 (Kg)	Direct distance
1	244,302,660,000	546,078.70	0.6732
2	585,887,840,000	1,668,097.20	1.4000
3	696,091,150,000	1,668,201.40	1.8510
4	530,853,560,000	1,647,855.80	1.1868
5	309,109,916,000	1,557,448.80	0.3332
6	422,520,521,000	1,617,602.00	0.7615
7	723,201,360,000	1,671,013.90	1.9603
8	369,105,076,000	1,587,422.60	0.5609
9	475,413,938,000	1,628,713.50	0.9713
10	384,336,724,000	1,609,001.10	0.6103
11	461,892,289,000	1,625,790.00	0.9177
12	290,295,218,000	1,551,694.80	0.2597
13	267,938,562,000	1,487,944.40	0.2063
14	251,370,881,000	873,756.80	0.5060
15	262,044,123,000	1,067,612.40	0.4337

Table 3 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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