

Genetic Algorithm Based Multi-objective Optimization of Wheat Flour Supply Chain Considering Raw Material Substitution

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Abstract—The aim of this study was to develop multi-objective optimization model for wheat flour supply chain. The model was developed by considering raw material substitution with local flour. The local flour such as mocaf, tapioca, sweet potato, modified corn flour etc. can substitute a part or whole of wheat flour for wheat flour-based product application. However, raw material substitution can impact supply chain network, raw material supply policy, and product quality so that it is important to optimize supply chain for that case. In this work, we used mocaf as flour substitution for wheat flour in wheat flour mill. We developed multi-objective supply chain model that minimized total cost and maximized product quality. Genetic algorithm approach was used to solve the optimization problem. For numerical experiment, we used supply chain configuration consisting of three wheat suppliers, three mocaf suppliers, three wheat flour mills, four distribution centers, and two food factories.

Keywords: multi-objective optimization, supply chain, raw material substitution, genetic algorithm

I. INTRODUCTION

ODAY, **T**Indonesia is the second largest wheat importer country after Egypt. Wheat flour consumption in Indonesian continues to increase every year. According data [1] from Indonesian wheat flour producer association (Aptindo) for 2013, Indonesian wheat flour consumption reach as much as 5.43 million metric tons (MT).

The role of wheat flour is important in Indonesia for food resilience, economics and politics so that it is necessary to reduce dependency on wheat (flour). Some efforts have conducted to reduce wheat import in Indonesia such as developing wheat agricultural but it failed. Another effort is conducting wheat substitution with native Indonesian flour such as tapioca, modified cassave flour (mocaf), sweet flour, corn, sago, buckwheat flour, etc.

Substituting of a part or whole of wheat flour by local flour can impact toward supply chain policies. Substitution policy makes company use multi-sources so that impact to supply chain decision. Previous work about substitution was carried by Lu [2] that used multi-source and substitution strategy to reduce impact of supply chain disruption. Because wheat commodity involves global supply chain so that susceptible toward supply disruption. Raw material substitution in wheat

flour production can reduce impact of supply chain disruption. In other hand, substitution need multi-source to supply raw material. Wheat flour substitution also can increase supply chain cost and decrease product quality. Richana [3] state that wheat flour substitution with local flour in certain amount can reduce product quality both taste and nutrition.

Previous studies about product substitution most describe consumer driven substitution (demand substitution). This consumer driven substitution occurs because ordered product by consumer is not available and usually firm offers the other similar product as replacement ordered product. Optimization of production with substitution considering conducted by [4] for multi product and single period. Production optimization model of a single-period, multiproduct, downward substitution which has one raw material as the production input and produces N different products as outputs [5]. The demands and yields for the products are random.

According to Chopra [6], supply chain is a sequence of processes and flows that take place within different supply chain stages and to satisfy a customer need for a product. A supply chain consists of a set of facilities, suppliers, customers, products and method of inventory control, procurement and distribution. The chain connects suppliers which produce raw material (product) and customers as end product user [7]. There are some decisions in supply chain management that is using to by decision maker. The decision involves: production, inventory, location and facility alternative, transportation and information.

In the real world, supply chain problems often face some objectives to be attained simultaneously which sometime there is conflict occur. In this case, we can see that problems such as in plant location alternative decision which objectives to minimize total cost of supply chain, but in order hand to attain minimum product delivery time to consumer.

To fulfill several objectives in supply chain design by considering raw material substitution in wheat flour supply chain, it needs to be solved by multi-objective optimization.

There are many studies about multi-objective optimization of supply chain have conducted before, but there have not been considering raw material substitution as explained earlier. In [7] designed supply chain network for plastic based

product that aims to minimize total cost, maximize customer service, and minimize capacity utilization ratio. Azaron et al. [8] developed supply chain design considering uncertainty condition with multi-objective stochastic programming approach. Optimization green supply chain conducted by [9], [10] that aimed to minimize total cost and gas emission. Moncayo–Martínez dan Zhang [11] carried out optimization of each echelon of supply chain with objectives to minimize total cost and lead time.

Many studies about multi-objective optimization for supply chain had been conducted before, but no study considered raw material substitution. That motivates us to perform multi-objective optimization for supply chain considering raw material substitution. In this study, multi-objective optimization aims to obtain optimal supply chain design that fulfill two objectives, i.e. minimize total cost and maximize product quality.

II. LITERATURE REVIEW

A. Multi-objective Optimization

Multi-objective optimization (MOO) is optimization problem that has objective function more than one. Those objectives attained simultaneously which between those objectives sometimes there is conflict occur. In general, multi-objective optimization problems can be formulated as follow:

Minimize/maximize

$$F(\mathbf{x}) = [F_1(\mathbf{x}), F_2(\mathbf{x}), \dots, F_k(\mathbf{x})]^T$$

$$\text{Subject to } g_j(\mathbf{x}) \leq 0, j=1, 2, \dots, m, \quad (1)$$

$$h_l(\mathbf{x}) = 0, l=1, 2, \dots, e,$$

where k is objective function number, m is inequality constraint number, and e is equality constraint number. $\mathbf{x} \in E^n$ is decision variable vector, which n is independent variable (x_i) number x_i .

According to Konak et al. [12], there are two general approaches for solving MOO problems. The first approach is to combine all objective functions to form a single function or move all of the objective functions but one objective move to constrain sets. There are several methods for this approach that we can see in literatures, such as the weighted-sum method [13], [14], the ϵ -constraint method [15], [14], lexicographic [14], LP- metrics method [16], goal-programming method [17], etc.

The second approach is to determine all Pareto-optimal set as solution not dominated by the others. In MOO problem, a decision maker face to Pareto-optimal solutions that constitute set of trade-offs between different objectives [12]. In mathematic, a feasible solution x_1 in MOO called 'dominate' $f_i(x_1) \leq f_i(x_2)$, $i = 1, 2, \dots, N$ and $f_j(x_1) < f_j(x_2)$ for at least one objective function. A solution non-dominated by other solution called Pareto-optimal. Non-dominated solution is if there are no solution that increases performance measure simultaneously without causes to decrease performance at least one the other objectives [18]. Set of all non-dominated

solutions called set with Pareto-optimal and objective value relating for set.

B. Supply Chain Management

Supply chain constitutes a facility and alternative distribution network that conducts function of material procurement, transform raw material to intermediate or final product, and distribute the product to costumers [19]. Supply chain management manages material and information flows between those facilities i.e. supplier, plant, warehouse, and distributor [20]. In supply chain management, there are several decisions that usually be taken by company. The decisions involve i.e. 1) production, 2) inventory, 3) location selection for facilities, 4) transportation, and 5) information.

There are many supply chain problems solved by multi-objective optimization approach that had been conducted by researchers. In [21], [22] developed multi-objective model for supplier selection to fulfill multicriteria. Research developed Multi-objective model for supply chain in various configuration and design. Sarrafha et al. [23] developed multi-objective model for designing supply chain with multi period involves supplier, plants, DCs, and retailer. In [24] developed supply chain network with multi period, multi product and multi channel network. In [7], [25] developed supply chain network involving multiple suppliers, plants, and distribution centers (DCs).

III. PROBLEM STATEMENT

Generally, large modern as well as small and medium food Industries in Indonesia base on wheat flour such as instant noodle, biscuit, cookies, bread, etc. In order to reduce the use of wheat flour in food industry, until now have been conducted many researches about local flour (native Indonesian flour) that can substitute wheat flour. Until now, several local flour have been developed to substitute a part or whole wheat flour such as mocaf, tapioca, sweet potato, modified corn flour, etc. If wheat flour substituted with local flour then can reduce wheat flour usage in food industries. Furthermore, that can reduce the impact of disruption caused by disruption supply from importer countries.

To support government's program on National food security, it is necessary to reduce wheat import. Food factories are driven to substitute a part of wheat flour with local flour. In this study, substitution carried out in wheat flour plant a maximum 15% of the use of wheat flour. This study discusses wheat flour supply chain considering raw material substitution. Local flour used to substitute wheat flour is mocaf (modified cassava flour). Generally, mocaf plant produced in small capacity plant so that needed some mocaf supplier to fulfill wheat flour plant requirement.

This substitution affects the wheat flour supply chain due to the addition of mocaf supplier. Furthermore, raw material substitution also impacts toward inventory policy, product quality, and reliability supply chain. New wheat flour supply chain network considers local flour substitution can be showed at Figure 1.

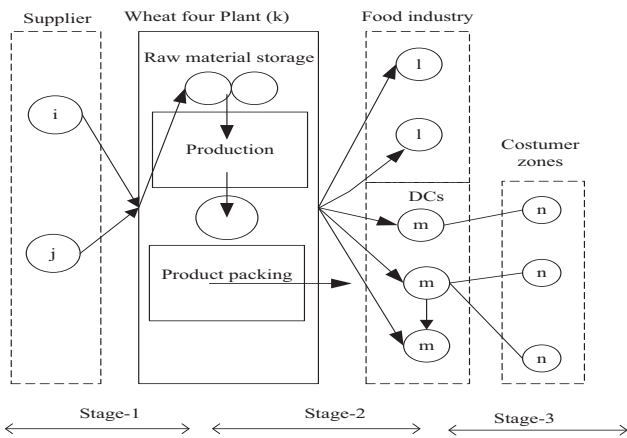


Fig. 1. Wheat flour supply chain considering local flour substitution

Wheat flour mill orders raw material from Australia, Canada and India. Plant capacity is 2200 metric ton per day (MT/day). Raw material of wheat stored in storage tank before be milled to become wheat flour. In production process, wheat flour mixed with mocaf to get compound flour. There are three mocaf supplier sources. Wheat flour as final product is stored in storage tank before being packed and then distributed to the food factories and distribution centers. In this case, we optimized supply chain network involving optimal amount of wheat and mocaf shipped from supplier to flour mill and optimal amount of wheat flour shipped from flour mill to DCs and food factories as well as maximum percentage of mocaf to be mixed.

I. MODEL FORMULATION OF MULTI-OBJECTIVE OPTIMIZATION

Formulation of mathematical model of multi-objective optimization for this supply chain is assigned to fulfill two objectives. The objectives for this study are to minimize total cost supply chain and maximize product quality. Supply chain optimization aims to determine amount of raw material that sent from supplier to the wheat flour plant and amount of product that allocated to distributors and food industries. Futhermore, mathematical model formulated to determine a maximum percentage of mocaf mixed with wheat flour to fulfill all constraints.

A. Assumptions

Some assumptions needed in this study to simplify formulating mathematic model, i.e.:

1. Wheat flour substitution with local flour conducted in wheat flour mill.
2. Local flour is substituted maximum to a maximum of 15%.
3. Local flour used to substitute wheat flour is mocaf.
4. Investation cost to install the additional machines or facilities be ignored.
5. Using single-product and single-period planning horizon for supply chain configuration in numerical experiment.
6. The raw material price used is the prevailing price when this study was running.

7. The import price of raw material includes landing charge, customs duty, clearing charges and special additional duty.

B. Notations, Variables and Parameters of Model

The following notations are used for the mathematical formulation for optimization multi-objective model.

Sets and indices:

- i = Index of wheat supplier ($i \in I$)
- j = Index of mocaf supplier mocaf ($j \in J$)
- k = Index of wheat flour mills ($k \in K$)
- l = Index of food factory ($l \in L$)
- m = Index of distributors ($m \in M$)
- n = Index of customer's zone ($n \in N$)

Decision variables:

- G_{ikt} = Amount of wheat transported from supplier i to wheat flour mill k at period t
- M_{jkt} = Amount of mocaf transported from supplier j to wheat flour mill n at period t
- Mp = Percentage of mocaf used to substitute wheat flour
- Q_{klt} = Amount of product transported from wheat flour mill k to food factory l at period t
- D_{kmt} = Amount of product transported from wheat flour mill n to DC m at period t

Model parameters:

- CP_{kt} = Capacity of wheat flour mill n at period t
- CG_{it} = Capacity of wheat supplier i at period t
- CM_{jt} = Capacity of mocaf supplier j at period t
- OG_{ik} = Ordering cost of wheat from supplier i to wheat flour mill k
- OM_{jk} = Ordering cost of mocaf from supplier j to wheat flour mill k
- PG_i = Wheat price from supplier i
- PM_j = Mocaf price from supplier j
- DF_{klt} = Amount of product sent from wheat flour mill k to food factory l at period t
- DT_{kmt} = Amount of wheat flour sent from flour mill k to DCs m at period t
- D_{klt} = Demand from food factory l to wheat flour mill k at period t
- U_{lt} = Amount of wheat flour usage in food factory l at period t
- DC_{kmt} = Demand from DCs m to wheat flour mill k at period t
- TP_{klt} = Transportation unit cost from flour mill k to food factory l at period t
- TD_{kmt} = Transportation unit cost from flour mill k to DCs m at period t
- TP_{rkt} = Total resulted product at flour mill k at period t
- R = Utility of raw material of wheat per unit product
- HW_{kt} = Holding cost of wheat in wheat flour mill k at period t
- Hm_{kt} = Holding cost of mocaf in wheat flour

- $H_{p_{kt}}$ = mill k at period t
= Holding cost of wheat flour in wheat flour mill k at period t
- $H_{p_{lt}}$ = Holding cost of wheat flour in food factory l at period t
- $H_{p_{mt}}$ = Holding cost of wheat flour at DCs m at period t
- HG_i = Wheat price at supplier i
- HM_j = Mocaf price at supplier j
- a, b, = Regression coefficient (relation of percentage of mocaf that substituted to wheat flour)

C. Objective functions

There were two objectives to be optimized in this supply chain optimization, i.e. to minimize total cost and maximize product quality.

Objective 1: Minimization of supply chain total cost. Total cost of supply chain involves raw material purchasing cost (PC), transportation cost (TrC), and holding cost (HC) or be written as follows:

$$\text{Min } f_1 = PC + TrC + HC \quad (2)$$

Involved cost in supply chain can be described as follows:

Purchasing cost (PC)

Raw material purchasing cost determined by multiplying of the price by the amount raw material purchased. Purchasing cost can be formulated as follows:

$$\sum_i \sum_k \sum_t G_{ikt} HG_i + \sum_j \sum_k \sum_t M_{jkt} HM_j \quad (3)$$

Transportation cost (TrC)

Transportation cost is amount of unit product multiply by transportation cost per unit product. Transportation cost consist of transportation from flour mill to DCs and food factory that can be formulated as follows:

$$\sum_k \sum_l \sum_t DF_{klt} TP_{klt} + \sum_k \sum_m \sum_t DT_{kmt} TD_{kmt} \quad (4)$$

Holding cost (HC)

Holding cost defined as money spent to keep and maintain a stock of raw material or goods in storage. Total holding cost in supply chain (HC)= holding cost at flour mill k (HC_k)+ holding cost at food factory l (HC_l)+ holding cost at DCs m (HC_m).

Holding cost can be determined by multiplying amount of inventory of raw material or product with holding cost per unit per period. Amount of inventory at plant or DCs formulated by amount of product received then reduced by those usage at period t. In this study, amount of wheat usage at period t assumed with plant capacity (CP_{kt}). Amount of mocaf usage is percentage of maximum mocaf mixed to wheat flour. In wheat flour mill, holding cost involves raw material and product holding cost. Mathematical formulation of raw material holding cost in wheat flour mill (HrC) can be written as follows:

$$\sum_t Hw_{kt} (\sum_i \sum_k \sum_t G_{ikt} - \sum_k \sum_t CP_{kt}) + \sum_t Hm_{kt} (\sum_j \sum_k \sum_t M_{jkt} - Mp \sum_k \sum_t CP_{kt}) \quad (5)$$

Holding cost occurred in wheat flour mill because amount product produced more than sent product at period t. Wheat flour produced at flour mill as much as 75% of raw material. Local flour mixed to wheat flour maximum of 15%, so that result product total can be formulated, as follows:

$$TP_{r_{kt}} = \alpha CP_{kt} + \beta(a/(1-\beta) CP_{kt}) \quad (6)$$

Where,

α = conversion coefficient of raw material to product

β = Percentage of local flour mixed to wheat flour

$$TP_{r_{kt}} = 0.75CP_{kt} + 0.15(0.75/0.85CP_{kt})$$

$$TP_{r_{kt}} = 0.88 CP_{kt} \quad (7)$$

Mathematical formulation for holding cost of product at wheat flour mill (HC_k) can be written as follows:

$$\sum_k \sum_t H_{p_{kt}} (\sum_k \sum_t TP_{r_{kt}} - (\sum_k \sum_l \sum_t DF_{klt} + \sum_k \sum_m \sum_t DT_{kmt})) \quad (8)$$

Mathematical formulation for holding cost of product at food factories (HC_l) can be written as follows:

$$\sum_l \sum_t H_{p_{lt}} (\sum_k \sum_l \sum_t DF_{klt} - \sum_l \sum_t U_{lt}) \quad (9)$$

Mathematical formulation for holding cost of product at DCs (HC_m) can be written, as follows:

$$\sum_m \sum_t H_{p_{mt}} (\sum_k \sum_m \sum_t (DT_{kmt} - \sum_m \sum_n \sum_t UD_{mnt})) \quad (10)$$

Total holding cost in supply chain refers to (5) to (10), can be written as follows:

$$HC = HrC + HC_k + HC_l + HC_m \quad (11)$$

Objective 2: maximize product quality

A part substitution of wheat flour by local flour can impact product quality i.e. taste, swelling power, product appeal. In this study, product quality determined by organoleptic test that uses man sense to quantify texture, apparent, taste, attraction of food product. The organoleptic test in this study used panelists perception about food product test that using substitution flour.

Product quality equation based on regression relation of percentage of used substitution flour on product quality. Mathematical formulation can be written as follows:

$$\text{Max } f_2 = a + b.Mp \quad (12)$$

To simplify model, Mp can be described as amount of mocaf transported from supplier j to wheat flour mill n at period t ($\sum M_{jkt}$) divided by amount of wheat transported from supplier i to wheat flour mill k at period t ($\sum G_{ikt}$) or written as $Mp = \sum M_{jkt} / \sum G_{ikt}$.

D. Model Constraint

The constraints were used in this study i.e.:

- Constraint of production capacity of wheat flour mill.

$$R \sum_i \sum_t G_{ikt} + R \sum_j \sum_t M_{jkt} \leq CP_k, \quad \forall k \quad (13)$$

- Constraint of wheat supplier capacity (wheat total demand

$$\sum_k \sum_t G_{ikt} \leq CG_i, \quad \forall i \quad (14)$$

- Constraint of mocaf supplier capacity (mocaf total demand of wheat flour mill is not exceed capacity of supplier j)

$$\sum_k \sum_t M_{jkt} \leq CM_j, \quad \forall j \quad (15)$$

- Constraint of maximum percentage of usage substitution flour.

$$Mp \leq 0.15 \quad (16)$$

- Amount of raw material received by wheat flour mill must be larger than demand of food factory and DCs.

$$\sum_i \sum_t G_{ikt} + \sum_j \sum_t M_{jkt} \geq \sum_l \sum_t D_{klt} + \sum_m \sum_t Dc_{kmt}, \quad \forall k \quad (17)$$

- Constraint of decision variable:

$$G_{int} \geq 0, \quad \forall i, M_{jnt} \geq 0, \quad \forall j, Q_{nit} \geq 0, \quad \forall n, D_{nmt}, \quad \forall n$$

Multi-objective optimization model above was solved using genetic algorithm (GA) approach which showed in the next section.

I. RESULTS AND DISCUSSION

For numeric experiment, we used supply chain configuration i.e. 3 wheat suppliers, 3 mocaf suppliers, 3 wheat flour mills, 4 DCs, and 2 food factories.

Solving multi-objective problem in this study, we used multi-objective software to get Pareto front set. This multi-objective software uses a variant of NSGA II [18] or called by modified NSGA II for solving multi-objective problems.

Generally, procedure of modified NSGA II describe as follows [26]:

1. Initialize population

Population is initialized based on the problem range i.e number of decision variables, number of objective functions and constraints if any. A chromosome represents all needed variables including units transported from supplier to flour mill and unit units transported from plant to DCs and food factory. Each gene represents a single variable (decision variable) as a real number. In this study, number of variables are 36.

2. Sort non-dominated

The initialized population is sorted based on non-domination. An individual dominate another if its objective functions is no worse than the other and at least in one of its objective functions is better than the other. The non-dominated identified to classify fronts F_1, F_2, \dots, F_R in R_t . The first front (F_1) is a non-dominant set for current population and the second front (F_2) is dominated by the individuals in the first front only and goes so on for the next front.

3. Generate offspring population

Offspring generated by genetic operator i.e. crossover and mutation that performed on entire population. In this study

of wheat flour mill is not exceed capacity of supplier i) crossover function use two- point with rate 0.8 and mutation function use uniform with rate = 0.01.

The other parameter settings were performed in this experiment, as follows:

Population type = double vector

Population size = 200

Selection function = tournament, size= 2

Generation size = 3600

The results are presented for generation sizes of 3600. The result of trade off between objective function 1 and 2 are presented as Pareto front set as showed at Fig. 2.

We can indicate from Fig. 2 that minimum supply chain total cost is \$778664.05 and maximum product quality is 4.48 or called Pareto front optimum. Decision maker can design optimum supply chain that can fulfill two-determined objectives bases on Pareto front optimum.

Chromosome length in this model is as many as decision variable i.e. 36 gens. In this case, it makes execution time need longer time. Therefore, for furthermore experiment, we recommend to use efficient representation for transportation/distribution problems such as which developed by [27] that used priority-based encoding in GA.

In search of the optimal solutions, we recommend to perform the experiments under varying sizes of population and the number of generations as well as varying genetic operator setting. For uncertainty environment condition, we recommend to integrate fuzzy logic and multi-objective optimization such as framework developed by Yandra [28]. More over non-numeric method may be considered in selecting the significant factors being investigated [29].

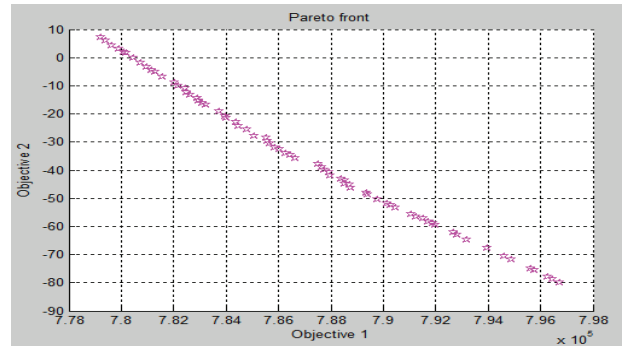


Fig. 2. Pareto front set between objective 1 and objective 2 for population size=200 and generation=3600

II. CONCLUSION

This paper presented multi-objective model for supply chain optimization considering raw material substitution. Two objectives were considered i.e. total cost minimization and product quality maximization. Genetic algorithm approach was used to get Pareto front set in multi-objective for supply chain problem. Pareto front set can be used by the decision maker to design the optimal supply chain considering raw material substitution by many solution alternatives.

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