MULTI OBJECTIVES FUZZY ANT COLONY OPTIMIZATION DESIGN OF SUPPLY PATH SEARCHING

Ditdit N. Utama[1], Taufik Djatna[2], Erliza Hambali[2], Marimin[2], and Dadan Kusdiana[3]

[1]Information Systems Department, Faculty of Science and Technology, State Islamic University, Jakarta, 15412, Indonesia
[2]Postgraduate Program of Agro-Industrial Technology, Graduate School of Bogor Agricultural University, Bogor, West Java, 16680, Indonesia
[3]Directorate of New Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources, Jakarta, 10110, Indonesia

E-mail: dit.utama@uinjkt.ac.id

Abstract

One of problem faced in supply chain management is path searching. The best path depend not only on distance, but also other variables, such as: the quality of involved companies, quality of delivered product, and other value resulted by quality measurement. Commonly, the ant colony optimization could search the best path that has only one objective path. But it would be difficult to be adopted, because in the real case, the supply path has multi path and objectives (especially in palm oil based bioenergy supply). The objective of this paper is to improve the ant colony optimization for solving multi objectives based supply path problem by using fuzzy ant colony optimization. The developed multi objectives fuzzy ant colony optimization design was explained here, that it was used to search the best supply path.

Keywords: *multi objectives fuzzy ant colony optimization design, supply path searching, supply chain management*

Abstrak

Salah satu masalah yang dihadapi dalam *Supply Chain Management* adalah pencarian jalur. Jalur terbaik tidak hanya tergantung pada jarak, tetapi juga variabel lain, seperti: kualitas perusahaan yang terlibat, kualitas produk yang dikirimkan, dan nilai lain yang dipengaruhi oleh pengukuran kualitas. Umumnya, *Ant Colony Optimization* bisa mencari jalur terbaik yang hanya memiliki satu jalur objektif. Tapi akan sulit untuk diadopsi, karena dalam kasus nyata, jalur *supply* memiliki banyak jalur dan tujuan (khususnya pasokan minyak kelapa sawit berbasis bioenergi). Tujuan dari penelitian ini adalah untuk meningkatkan *Ant Colony Optimization* dalam menyelesaikan masalah jalur *supply* dengan menggunakan *Fuzzy Ant Colony Optimization*. Tujuan pengembangan *Fuzzy Ant Colony Optimization* dijelaskan disini, yaitu digunakan untuk mencari jalur *supply* terbaik.

Kata Kunci: *desain fuzzy ant colony optimization, pencarian jalur supply, supply chain management*

1. Introduction

In recent years, there are many researchers have been done in many fields. Rules design for diagnosis of diabetes disease [1-3], model design for detect Retina Vessel [4]; the application of soccer robot [5]; routing protocol model for mobile ad hoc network case [6]; the model for optimizing of network topology design [7]; are some examples of research in many fields that used Fuzzy Ant Colony Optimization (FACO) as their main method.

Furthermore, many researches above used only a single objective as goal of artificial ant in searching the best solution, especially in fuzzy environment. It would be more fruitful if the artificial ant of the model could search the best solution of many solution alternatives that indicated multi objectives of the fuzzy model.

On the other hand, the multi objectives of fuzzy ant colony optimization model would be easier implemented in the real supply chain problem, especially in palm oil based bioenergy supply chain case. In Ant Colony Optimization theory, the ants' nest indicated the first level of

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supply chain (the first supplier, in palm oil based bioenergy supply chain case indicated farmers or plants), and the food was searched by ants indicated the end customer of supply chain. In the real case of supply chain case, especially in palm oil based bioenergy supply chain, the supplier and the end customer must be indicated by more than one item. Finally, this paper would explain the model developed by using Multi Objectives Fuzzy Ant Colony Optimization (MOFACO) method. Here, FACO model have been modified to be Multi Objectives FACO model. It would be implemented in palm oil based bioenergy supply chain.

Supply chain concept is still a growing concept in logistic problem view. In a conventional concept, logistic problem has been seen as internal company problem only. The companies have to solve their problems internally and solely, without collaborate to their company partners. In this new one, logistic problem is seen as a boarder problem. The logistic problem can be happen in every step of supply chain, from the first level up to the last level of supply chain. That is reason why supply chain management can be defined as a set of approaches utilized to efficiently integrate suppliers, manufactures, warehouse, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, at the right time, in order to minimize system wide costs while satisfying service level requirement [8]. Figure 1 described supply chain management concept.

On the other hand, in a supply chain is the alignment of firms that bring products or services to market." from Lambert, Stock, and Ellram [9]. The supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves [10]. The other definition said that the supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers [11].

Guthjar [12] said that ACO is an optimization technique inspired by observations on the behavior of biological ant colonies; it has been introduced by [13], and [14]; and developed later into a meta-heuristic for combinatorial optimization problems [15-17]. Recently, ACO algorithms have also turned out as competitive in a discrete stochastic optimization context [18-22]. Furthermore, an ACO is essentially a system based on agent, which simulates the natural behavior of ants including mechanisms of co-operation and adaptation. To use this kind of system, a new meta-heuristics proposed in order to solve combinatorial optimization problems. This new meta-heuristic has been shown to be both robust and versatile in the sense that it has been successfully applied to arrange of different combinatorial optimization problems. ACO algorithms are based on following ideas [23]: (1) Each path, is followed by an ant, is associated with a candidate solution for a given problem. (2) When an ant follows a path, the amount of pheromone deposited on that path. This path is proportional to the quality of the corresponding candidate solution for the target problem. (3) When an ant has to choose between two and more paths, the path with a larger amount of pheromone has a greater probability of being chosen by the ant.

Fuzzy Ant Colony Optimization combines Ant Colony Optimization with Fuzzy Performance Variable. In this case, there are three variables of performance variables that can be identified by using Fuzzy logic, they are: Performance of human resource, value added and transportation cost. This fuzzy logic could improve the previous variables value (ACO based variables value) representation.

2. Methodology

Actually, the basic thinking of this research is model development for the most optimum searching in one supply chain. There are seven steps of research. The first step is the supply chain partnership identification. In this step, we identified all partners involved in bio-energy supply chain business process. The first step's result could be used to develop supply network (the second step). Principally, these two steps mentioned to make us more understand about bio-energy supply chain configuration, especially palm oil based bio-energy.

Furthermore, in third step, we identified all variable needed to measure performance, both supply chain element performance and supply chain performance. Before we measured the performance of supply chain element and supply chain (step 5 and 6), we processed all variables by using fuzzy logic method (step 4). Finally, we developed model for searching the most optimum path of supply chain.

Formally, data were collected by using observation, survey, literature study, Supply Chain Operations Reference method [24][25] to develop supply chain network map. We did some observations and survey in Riau Province, especially at Dumai and Kuala Enok Industrial

Area, Plantation Department, farmers and collectors. In fact, we did not get data fully according to we needed, so we generated them by using Monte Carlo Simulation method.

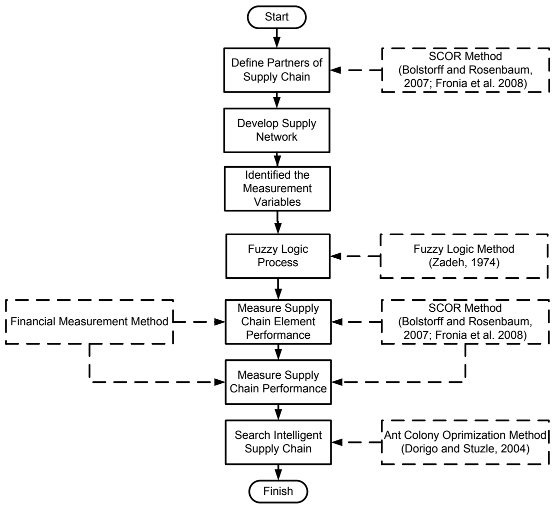

Figure 1. Research framework.

Moreover, SCOR method was used to measure supply chain elements performance and supply chain performance. On the other hand, financial method was used to combine to SCOR method in measuring supply chain element performance. But, before data were used for measurement, the data were converted to fuzzy number by using fuzzy logic method [26].

Finally, the main method was used in this research is Ant Colony optimization / ACO method [17]. This method was used to search the most optimum path in supply chain. In general, the combination of fuzzy data set and ACO method is the reason why we call this model as a fuzzy ant colony based generic model.

Theoretically, Ant Colony Optimization is a meta-heuristic in which a colony of artificial ants cooperates in finding good solutions to difficult discrete optimization problems. Cooperation is a key design component of ACO algorithms: The choice is to allocate the computational resources to a set of relatively simple agents (artificial ants) that communicate indirectly by stigmergy, that is, by indirect communication mediated by the environment. Good solutions are an emergent property of the agents' cooperative interaction [17].

Based on basic behavior of FACO model ([19]), we generate a generic mathematical model for supply chain performance measurement which was described in the equation (1) formula.

$$PoP_C = D_C \times \left(1 - \left[\frac{\sum PoV_{C-1}}{\sum ToV_{C-1}}\right]\right) \times (1 - \tau) \qquad (1)$$

Where:
PoP_C = Performance of Current Path
D_C = Current Distance, the basis of measurement
PoV_{C-1} = Performance of Previous Node
ToV_{C-1} = Total of Previous Node
τ = Pheromone amount

Furthermore, pheromones (τ) could be formulated by using mathematical statement in equation (2) [17].

$$\tau_{ij}(t) = \rho . \tau_{ij}(t-1) + (1-\rho) . \tau_0 - \varepsilon \qquad (2)$$

Where:
τ_{ij} = Pheromones between node i and j
τ_0 = Starting Pheromones
t = Node
ρ = Parameter, between 0 and 1
ε = Evaporation

In the basic mathematical formula, there are three variables includes. These variables were needed for measuring the performance of current path (PoP_C), they are: distance, performance of previous supply chain element, and pheromone. In addition, for measuring the performance of previous node (PoV_{C-1}), there are three other variables were calculated, they are: Performance of previous supply chain element ($PoSCE_{C-1}$); performance of previous added value ($PoAV_{C-1}$); and performance of transportation cost ($PoTC_{C-1}$). These variables could be seen in equation (3).

$$\sum PoV_{C-1} = PoSCE_{C-1} + PoAV_{C-1} + PoTC_{C-1} \qquad (3)$$

Performance of Supply Chain Element ($PoSCE_c$) depends on 6 other variables: Performance of SCOR ($PoSCOR$), performance of financial (PoF), performance of machine (PoM), performance of human resource ($PoHR$), quality of product (QoP) and performance of waste management ($PoWM$). The mathematical formula of could be seen in equation (4).

$$PoSCE_c = PoSCOR + PoF + PoM + PoHR + QoP + PoWM \qquad (4)$$

Actually, three variables of six variables are defined in fuzzy logic by using Triangular Fuzzy Number (TFN) format. They are performance of human resource, added value, and transportation cost. TFN was defined as type of membership function because real data set configured it.

Basically, we wanted to categorize the real data sets of added value variable to be three natural language categories (low, medium and high). Firstly, from real added value data sets and normalized value added data sets, we got the element value of membership functions between 0.10 (α_{min}) and 1.00 (α_{max}), it was called as confidence interval. It indicated the limitation of ordinal value. After that, we set the range of three natural language categories: 0.10 – 0.33 for low, 0.33 – 0.78 for medium, and 0.78 – 1.00 for high category. All categories were set according to element value range of membership function and point 0.55 ($\frac{\alpha_{min}+\alpha_{max}}{2}$) as a median of the second category (medium).

Secondly, after we set the range of three natural categories, we designed the disjoint interval. It meant, that we had to design that between two categories value, the overlap value had to be set. From this result, we could design the TFN. Clearly, TFN configuration could be described in figure 2.

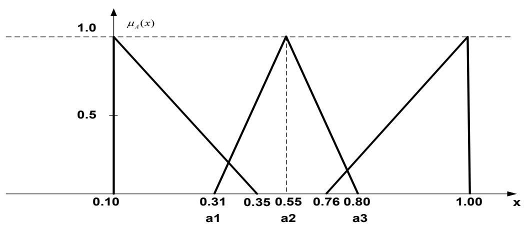

Figure 2. TFN of added value.

Where:

High $\mu_H(x) = \begin{cases} \frac{x-0.76}{0.76} & 0.76 < x \leq 1.00 \\ 1 & x \geq 1.00 \end{cases}$ .... (5)

$$\text{Medium } \mu_M(x) = \begin{cases} \frac{x}{0.35} & 0 < x \leq 0.35 \\ \frac{0.76-x}{0.35} & 0.35 < x \leq 0.76 \end{cases} \quad (6)$$

$$\text{Low} \mu_L(x) = \begin{cases} 1 & x \leq 0.1 \\ \frac{0.35-x}{0.35} & 0.1 < x \leq 0.35 \end{cases} \quad (7)$$

By using the same way, transportation cost performance TFN could be described in formula below.

$$\text{High } \mu_H(x) = \begin{cases} \frac{x-0.90}{0.90} & 0.90 < x \leq 1.00 \\ 1 & x \geq 1.00 \end{cases} \quad (8)$$

$$\text{Medium } \mu_M(x) = \begin{cases} \frac{x}{0.86} & 0 < x \leq 0.86 \\ \frac{0.90-x}{0.86} & 0.86 < x \leq 0.90 \end{cases} \quad (9)$$

$$\text{Low } \mu_L(x) = \begin{cases} 1 & x \leq 0.1 \\ \frac{0.86-x}{0.86} & 0.76 < x \leq 0.86 \end{cases} \quad (10)$$

Furthermore, for performance of human resource value, it has two variables that can be identified by using fuzzy logic in TFN format. They are: total of staff and experience average variable. Total of staff variable was identified by using TFN. It was described similar with figure 2 with confidence interval between 0.01 and 1.00 (mathematical formula could be explained in equation 11 up to 13). On the other hand, experience average variable was described similar with figure 2 with confidence interval between 0.16 and 1.00(mathematical formula could be explained in equation 14 up to 16).

$$\text{High } \mu_H(x) = \begin{cases} \frac{x-0.76}{0.76} & 0.76 < x \leq 1.00 \\ 1 & x \geq 1.00 \end{cases} \quad (11)$$

$$\text{Medium } \mu_M(x) = \begin{cases} \frac{x}{0.30} & 0 < x \leq 0.30 \\ \frac{0.76-x}{0.30} & 0.30 < x \leq 0.76 \end{cases} \quad (12)$$

Low $\mu_L(x) = \begin{cases} 1 & x \leq 0.01 \\ \frac{0.30-x}{0.30} & 0.01 < x \leq 0.30 \end{cases}$ ...(13)

High $\mu_H(x) = \begin{cases} \frac{x-0.74}{0.74} & 0.74 < x \leq 1.00 \\ 1 & x \geq 1.00 \end{cases}$ ..... (14)

$$\text{Medium } \mu_M(x) = \begin{cases} \frac{x}{0.38} & 0 < x \leq 0.38 \\ \frac{0.74-x}{0.38} & 0.38 < x \leq 0.74 \end{cases} \quad (15)$$

Low $\mu_L(x) = \begin{cases} 1 & x \leq 0.16 \\ \frac{0.38-x}{0.38} & 0.16 < x \leq 0.38 \end{cases}$ ⋯ (16)

Finally, the de-fuzzy value (μ_A) could be calculated by using mathematical formula below:

$$\mu_A = \begin{cases} 0, & x < a1 \\ \frac{x-a1}{a2-a1}, & a1 \leq x \leq a2 \\ \frac{a3-x}{a3-a2}, & a2 \leq x \leq a3 \\ 0, & x > a3 \end{cases} \quad (16)$$

Natural lingustic membership function of three fuzzy variables could be showed in table I. Table I explained that each representation of fuzzy variables have different weight with weight value between 0.00 until 1.00.

Based on formula (1) that combined with multi objective formula [27] in formula (17) and then changed to Fuzzy based multi objective formula (18), so mathematical model of multi objective based fuzzy ant colony optimization could be stated in formula (19). The best alternative of path decision consisted of m searching sources, n objectives, and o searching path (20).

TABLE I
LINGUISTIC SCALE VS WEIGHT

Variables	Linguistic Scale	Weight (ω)
Added Value Performance	High	$0.76 < x \leq 1.00$
	Medium	$0.35 < x \leq 0.76$
	Low	$0.10 < x \leq 0.35$
Transportation Cost Performance	High	$0.90 < x \leq 1.00$
	Medium	$0.86 < x \leq 0.90$
	Low	$0.76 < x \leq 0.86$
Staff Total	High	$0.76 < x \leq 1.00$
	Medium	$0.30 < x \leq 0.76$
	Low	$0.01 < x \leq 0.30$
Working Experience Performance	High	$0.74 < x \leq 1.00$
	Medium	$0.38 < x \leq 0.74$
	Low	$0.16 < x \leq 0.38$

$$\text{Min } Z = \sum_{n=1}^{\theta} f(X_n) \quad (17)$$

$$\text{Min } \tilde{Z} = \sum_{n=1}^{\theta} \tilde{f}(X_n) \quad (18)$$

$$\text{Min } \tilde{Z} = \sum_{n=1}^{\theta} \tilde{f}(J_c, KVN_n, JV_n, \tau) \quad (19)$$

$$\tilde{f}(J_{mno}, X_{mno}, Y_{mno}, \tau_{mno}) = \sum_{m=1}^{\theta}\sum_{n=1}^{\theta}\sum_{o=1}^{\theta}(J_{mno} \text{ x } (1 - \frac{\sum \tilde{X}_{mno}}{\sum Y_{mno}}) \text{ x } (1-\tau)) \quad (20)$$

Where:

J_{mno} = Starting point of searching (m) on objective (n) on path (o).

$\tilde{X}_{mno}$ = Performance of supply chain element on starting point (m) on objective (n) on path (o) (in *fuzzy*: high, medium, low; weight ω).

Y_{mno} = Amount of Supply chain element on starting point (m) on objective (n) on path (o).

τ = Pheromones.

The generic model was shown as aggregative variable class as shown in figure 3. This figure represented classes, namely AntGraph class, Ant class, and AntColony class. AntGraph class connected to SupplyChainPerformance class that consisted of: SCORPerformance class, and financialPerformance class. Fuzzification class was represented between transportationCostPerformance class, addedValuePerformance class, and humanResourcePerformance class with both supplyChainPerformance class and supplyChainElementPerformance class. Each class represented the name of main components in FACO model as an UML model. This model was assumed as a distance based model.

The detailed process flow of fuzzy ant colony based generic model could be described in figure 4. It was started at variable initiations, ants generating, up to supply chain performance value getting. The generic model is a part of intelligent decision support systems. This model is placed in model base sub-system of IDSS, it tightly relates to both database and interface sub-system. There are 9 types of data needed to generate the model: supply chain element, financial, SCOR, product, supply chain graph, human resource, machine, waste management, and AHP priority.

This generic model relates to other parts of model base sub-system, such as BSC – SCOR – AHP model, financial model, and SCOR model. This sub-system will generate the criteria priority, performance measurement and the most optimum path result. Especially for FACO model, it will generate the most optimum path of supply chain (figure 5).

3. Results and Analysis

Figure 6 showed that palm oil based bioenergy supply chain consisted of multi-layer of chain with multi sources and multi objectives, but for the example, it was showed only by two objectives. Point A indicated the farmers or plants, point B indicated the collectors, point C indicated CPO factories, point D indicated bioenergy factories, and point E indicated the end customers. All node of supply chain could be described based on map scale. It could be showed in figure 7.

Moreover, table II described the input data example base on fuzzy value for measuring performance of the supply chain node or element (equation 3) and human resource (one variable of equation 4). In addition, the de-fuzzy value of the performance of each element (SCOR, transportation cost, added value, financial, machine, human resource, waste management and product) could be shown by data in table III.

Finally, the result of model generation could be showed in table IV. The best path that has the best performance is the first path. It has 70.676 performance value, 292.749 distance value, and 0.076 pheromone value. The best performance could be showed in graphical chart (figure 8).

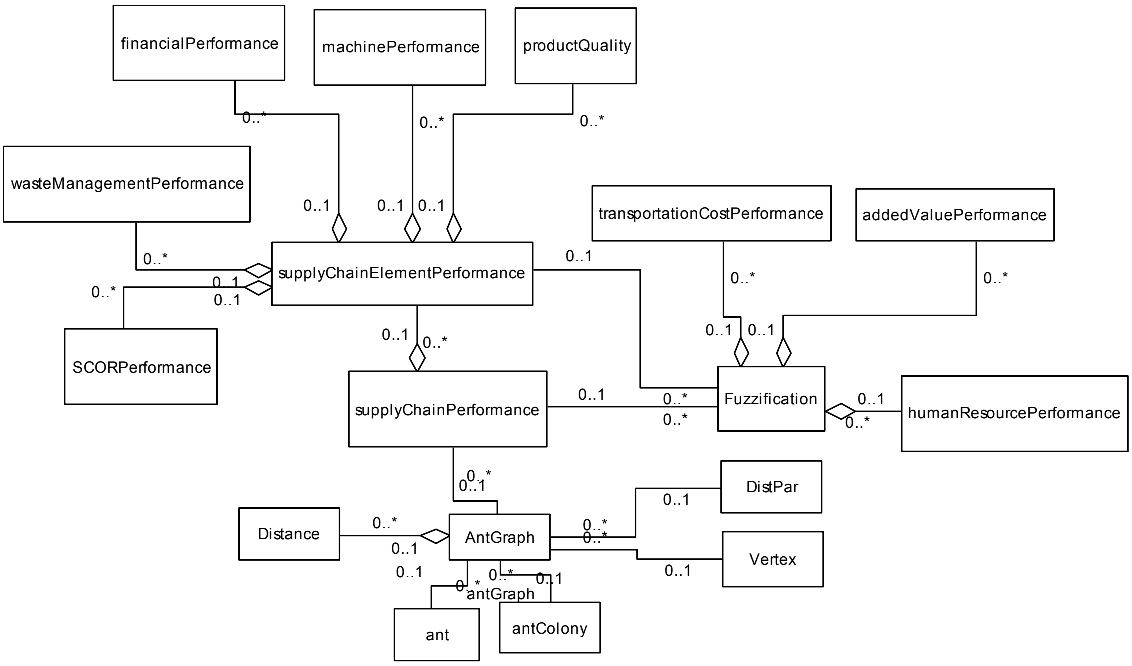

Figure 3. Class diagram of model.

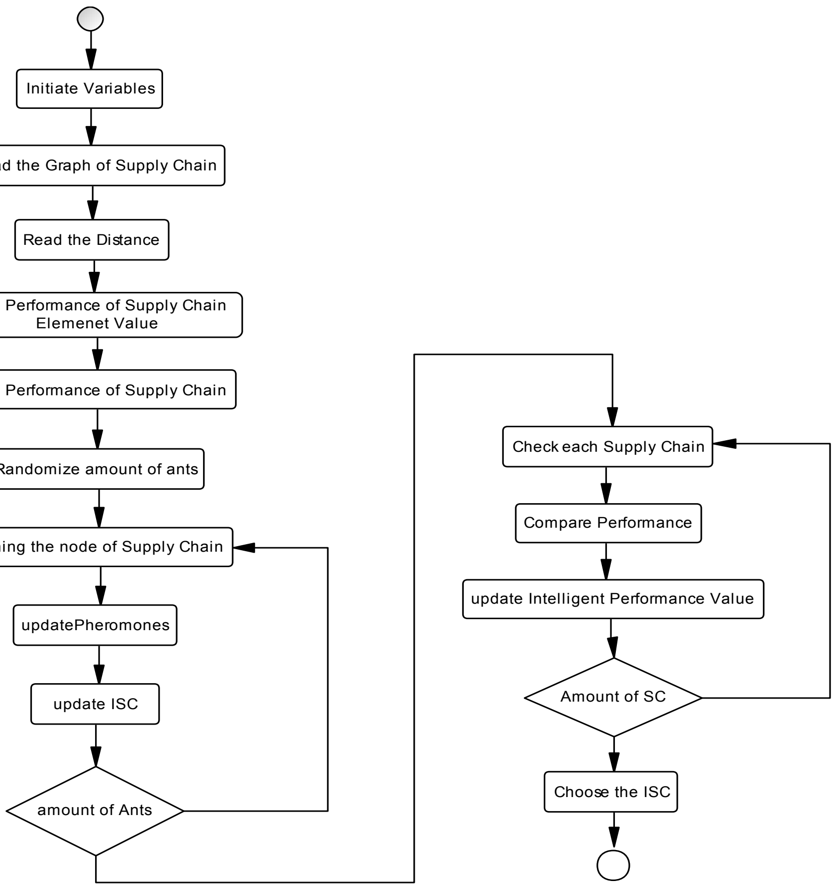

Figure 4. Activity diagram of model.

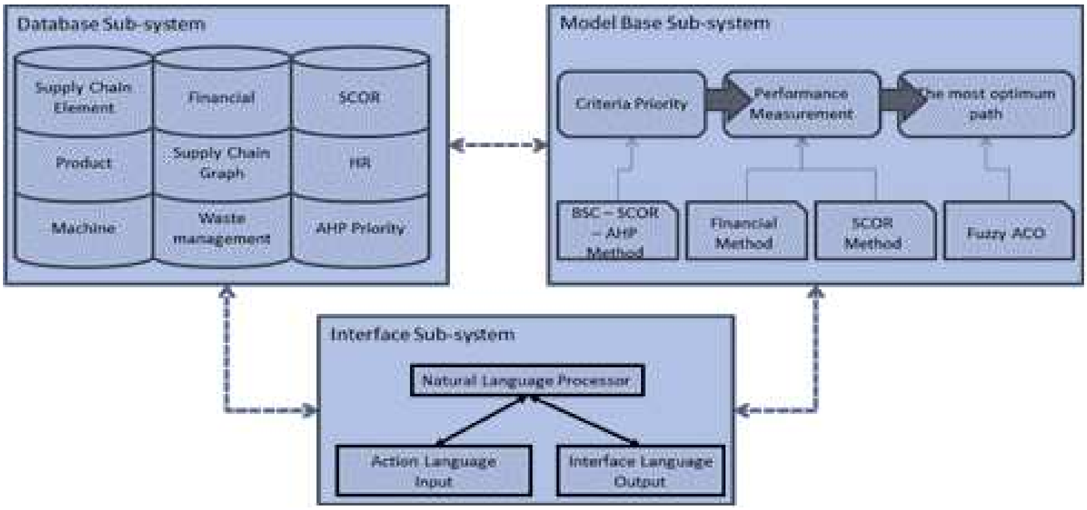

Figure 5. Model configuration.

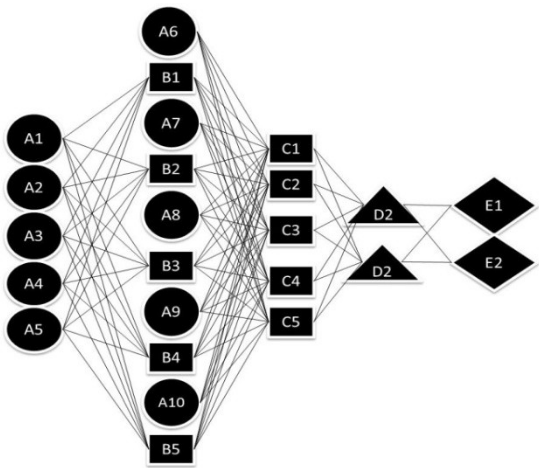

Figure 6. Chain of palm oil based bioenergy supply.

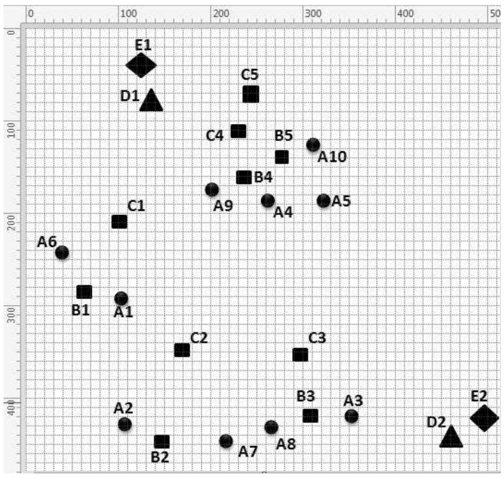

Figure 7. Supply chain node on map scale.

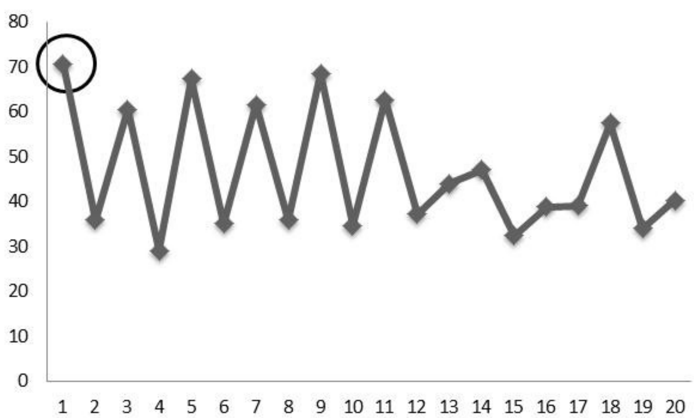

Figure 8. Line chart of supply chain performance.

TABLE II
FUZZY BASED INPUT DATA EXAMPLES

Node	Staff	Ex.	TC	AV
E1	-	-	-	-
E2	-	-	-	-
D1	Medium	Low	High	Medium
D2	Medium	Low	High	Medium
C1	Low	High	High	Medium
C2	Low	Medium	High	Low
C3	Low	Medium	Medium	Medium
C4	Low	Medium	High	Low
C5	Low	Medium	High	Medium
B1	Low	Medium	Low	Medium
B2	Low	Medium	High	Low
B3	Low	High	Medium	Medium
B4	Low	High	Low	High
B5	Low	High	High	Medium
A1	High	Medium	High	Medium
A2	High	Medium	Medium	Medium
A3	Medium	Medium	High	Medium
A4	High	Medium	Low	High
A5	Medium	Medium	High	Low
A6	Medium	Medium	High	Medium
A7	Medium	Low	High	Medium
A8	Medium	Medium	Medium	Medium
A9	Medium	Medium	High	Low
A10	Medium	Medium	Medium	Medium

TABLE III
DE-FUZZY PERFORMANCE VALUE

	SC	TC	AV	F	M	HR	WM	P
E1	-	-	-	-	-	-	-	-
E2	-	-	-	-	-	-	-	-
D1	0.43	1.0	0.08	0.5	0.5	0.5	1.0	0.7
D2	0.43	1.0	0.08	0.5	0.5	0.5	1.0	0.7
C1	0.62	1.0	0.22	0.7	0.5	0.5	1.0	0.5
C2	0.45	1.0	0.19	0.5	0.5	0.5	1.0	0.7
C3	0.85	1.0	0.19	0.7	0.5	1.0	0.0	0.5
C4	0.67	1.0	0.26	0.7	0.5	0.7	0.0	0.5
C5	0.64	1.0	0.23	0.7	0.5	0.5	0.0	0.0
B1	0.80	1.0	0.14	0.7	0.5	0.5	0.0	0.1
B2	0.47	1.0	0.11	0.7	1.0	0.5	0.0	0.1
B3	0.45	1.0	0.13	0.5	1.0	0.7	0.0	0.1
B4	0.87	1.0	0.26	0.7	0.5	0.7	0.0	0.1
B5	0.38	1.0	0.29	0.7	0.5	1.0	0.0	0.1
A1	0.72	1.0	0.03	0.7	1.0	0.5	0.0	0.1
A2	0.91	1.0	0.22	0.7	0.5	0.5	0.0	0.1
A3	0.63	1.0	0.04	0.7	1.0	0.5	0.0	0.1
A4	0.57	1.0	0.00	0.7	0.5	0.7	0.0	0.1
A5	0.52	1.0	0.33	0.5	0.5	0.5	0.0	0.1
A6	0.67	1.0	0.29	0.7	1.0	0.5	0.0	0.1
A7	0.68	1.0	0.33	0.7	0.5	0.5	0.0	0.1
A8	0.76	1.0	0.17	0.7	0.5	0.5	0.0	0.1
A9	0.53	1.0	0.03	0.5	0.5	0.5	0.0	0.1
A10	0.54	1.0	0.18	0.7	1.0	0.5	0.0	0.1

4. Conclusion

The Multi Objectives Fuzzy Ant Colony Optimization (MOFACO) could be implemented to search the best path, in palm oil based bioenergy supply chain, that combined with method of supply chain performance measurement. Model generated the best path with 70.676 performance value.

Furthermore, the next research could be focused on using other performance measurement of supply chain. On the other hand, combination of multi objectives fuzzy ant colony optimization and other algorithm methods would be interesting research.

TABLE IV
MODEL GENERATION RESULT

No	Supply Path	P	D	Ph.
1	A1 - B1 - C1- D1 - E1	70.676	295.749	0.076
2	A1 - B1 - C1 - D2 - E2	35.852	644.069	0.036
3	A6 - C1 - D1 - E1	60.608	396.588	0.06
4	A6 - C1 - D2 - E2	29.061	711.753	0.03
5	A4 - B5 - C4 - D1 - E1	67.398	328.538	0.069
6	A4 - B4 - C4 - D2 - E2	35.158	651.09	0.037
7	A9 - C4 - D1 - E1	61.599	386.679	0.062
8	A9 - C4 - D2 - E2	35.856	644.106	0.037
9	A5 - B5 - C5 - D1 - E1	68.604	316.631	0.076
10	A5 - B5 - C5 - D2 - E2	34.691	655.633	0.035
11	A10 - C5 - D1 - E 1	62.7	375.657	0.063
12	A10 - C5 - D2 - E2	37.24	630.201	0.037
13	A2- B2 - C3 - D1 - E1	44.039	562.028	0.039
14	A2 - B2 - C3 - D2 - E2	47.083	531.709	0.043
15	A7 - C2 - D1 - E1	32.372	678.783	0.033
16	A7 - C2 - D2 - E2	38.808	614.387	0.036
17	A3 - B3 - C2 - D1 - E1	39.063	611.735	0.035
18	A3 - B3 - C3 - D2 - E2	57.555	426.886	0.052
19	A8 - C2 - D1 - E1	34.018	662.119	0.031
20	A8 - C3 - D2 - E2	40.357	598.923	0.037

*P = Performance Value, D = Distance, Ph = Pheromones

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