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### Optimizing a Flexible Multi-Stage Logistics Network Model Using Imperialist Competitive Algorithm (ICA)

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#### Abstract

To be successful in today's active business competition, enterprises need to design and build a productive and flexible logistics network. The flexible multistage logistic network (fMLN) problem is NP-hard. The previous papers were considering the problem as a single source logistic network problem while in real world we face a multi source logistic network problem. This paper, tried to find the minimum cost of fMLN using Imperialist competitive Algorithm (ICA) with considering a multi source flexible multistage logistics network. Additionally, all product amounts shipped from plants to customer are obtained. The best product delivery route for each customer considering the constraints fulfilled will be found.

**Keywords:** Flexible Multistage Logistic Network (fMLN), Imperialist Competitive Algorithm (ICA).

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#### Introduction

One of the most strategic issues in supply chain management is the configuration of the logistics network with significant effects on the total performance of the supply chain (Pishvaei *et al* , 2009). Minimizing total costs is a traditional objective of a logistics network to answer customers' demands.

A complete logistics system covers the entire process of shipping raw materials and input requirements from suppliers to plants, the conversion of the inputs into products at certain plants, the transportation of the products to various warehouses or facilities, and the eventual delivery of these products to the final customer. To manage the logistics system efficiently, the dynamic and static states of material flows – transportation and storage – are key points to take into consideration. How to manage logistics system efficiently has thus become a key issue for many companies to control costs. That is also why an elaborately designed logistics network under the inference of today's fully-fledged information technology is calling more attention of business entities, especially of multinational companies. However, success seems difficult for these companies due to their huge and extremely complicated logistics networks, though they usually have a strong desire to cut down logistics cost (Gen *et al* , 2008).

The logistics network design problem is defined as follows: given a set of facilities including potential suppliers, potential manufacturing facilities,

and distribution centers with multiple possible configurations, and a set of customers with deterministic demands, determine the configuration of the production-distribution system between various subsidiaries of the corporation such that seasonal customer demands and service requirements are met and the profit of the corporation is maximized or the total cost is minimized (Goetschalckx *et al* , 2002).

To date the structures of the logistics network studied in all the literatures are in the framework of the traditional multistage logistics network (tMLN) model. There facilities are usually organized into four echelons (*i.e.*, plants, distribution centers (DCs), retailers and customers (Harland, 1997) in some order, and the product delivery routes should be decided during three stages between every two adjoining echelons sequentially.

This is the normal delivery in traditional logistics network from one stage to another adjoining one. Another method is called direct delivery or direct shipment, where goods move from plant to retailer directly and not via distribution centers, or sometimes the customer provides the goods from plant or from distribution center directly and not via retailer. For this type of delivery another logistic network is needed that we have nominated as Flexible Logistics Network. When this type of delivery is used for multi stage in logistic, that's name is flexible multi stage logistic network (fLMN)

(Gen *et al.*, 2008). Figure 1 shows the flexible multi stage logistic network.

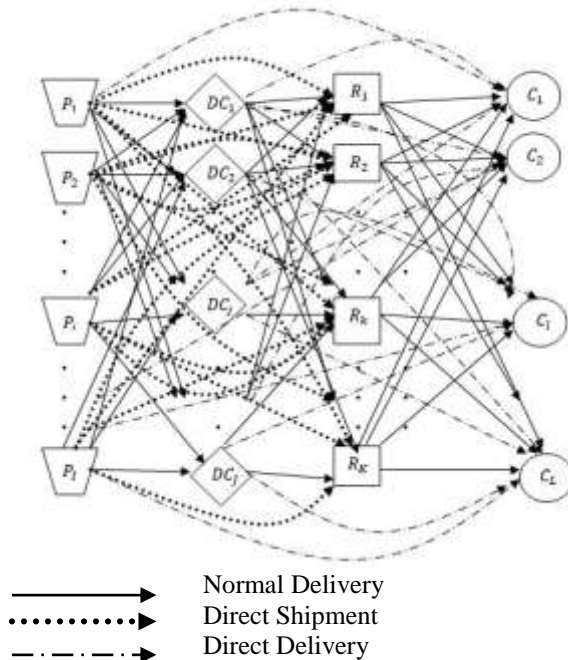


Figure 1: The structure of flexible multistage logistics network (fMLN) models (Gen *et al.*, 2008).

The trade-off between direct distribution and indirect distribution is also a critical issue in decision making in distribution channel in sales and marketing (Gen *et al.*, 2008).

A number of other papers exist displaying logistics network models and applying solutions such as GA, Tabu Search, and PSO (Particle Swarm Optimization) for optimization of the network.

(Shimizu *et al.*, 2006) applied a meta-heuristic method termed hybrid tabu-search to solve the flexible logistics optimization problem under uncertain demand forecasting. (Shimizu & Kawamoto, 2008), proposed a novel algorithm for parallel computing and using the PSO method.

(Nakatsu, 2005) described an intelligent system and showed how to utilize the model-based reasoning and heuristic-based search to guide an end-user towards more effective network designs. (Lin *et al.*, 2008) proposed a hybrid evolutionary algorithm (hEA) and new fuzzy logic control, and combined the local search to minimize the sum of transportation cost, inventory holding cost, fixed order cost and open cost of facilities. (Dullaert, 2005) suggested an evolutionary algorithm to determine the optimal combination of shipping alternatives to minimize total logistics cost. (Celik, 2004) realized the artificial neural networks as a very promising tool in predicting short-term inter-regional freight

distribution. (Shimizu *et al.*, 2008) developed a method termed hybrid tabu-search, and have applied it to various real-world problems through imposing proper conditions on the generic model.

(Lin *et al.*, 2007) proposed a hybrid genetic algorithm to solve the location-allocation model's problem of logistic network.

(Altıparmak *et al.*, 2006) presented mixed-integer non-linear programming model for multi-objective optimization of SCN and a genetic algorithm (GA) approach to solve the problem which was met on a producer of the plastic products in Turkey.

(Gen and Syarif, 2005) proposed a new approach called spanning tree-based hybrid genetic algorithm hst-GA to solve the multi-time period production/distribution and inventory problem (mt-PDI). (Gen *et al.*, 2006) proposed a GA called pb-GA, based on priority-based encoding method and a new crossover operator called the weighted mapping crossover (WMX) for two stage transportation problems in logistic network. (Bozorgi Rad *et al.*, 2013) proposed GA based solution techniques called RB-GA and HR-GA to solve variants of fMLN problems.

After over-viewing the literature on logistics network, this paper also address the problem of multi source (fMLN) and try to solve it using ICA and finally the comparison between the obtained results using normal GA and ICA will be shown.

### Flexible multistage logistics network model

This research utilizes the fMLN model formulated by Gen *et al.* (2008) as the base model. The model is formulated based on the following assumptions:

1. The single product case of a logistics network optimization problem is considered.
2. A single time period, such as one week or one month is considered.
3. In the logistics network, there are maximum four echelons: plants, DCs, retailers and customers.
4. There are three delivery modes: normal delivery, direct shipment and direct delivery, as mentioned above
5. Each customer is served by only one facility.
6. Customer demands are known in advance.
7. Customers will get products at the same price, no matter where she/he gets them. It means that the customers have no special preferences.

The following notations are used to formulate the mathematical model:

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**Notation:**

**Indices:**

$i$	index of plant ( $i = 1, 2, 3, \dots, I$ )
$j$	index of DC ( $j = 1, 2, 3, \dots, J$ )
$k$	index of retailer ( $k = 1, 2, 3, \dots, K$ )
$l$	index of customer ( $l = 1, 2, 3, \dots, L$ )

**Parameters:**

$I$	number of plants
$J$	number of DCs
$K$	number of retailers
$L$	number of customers
$P_i$	Plant $i$
$DC_j$	DC $_j$
$R_k$	Retailer $k$
$C_l$	Customer $l$
$B_i$	Output of plant $i$
$d_l$	Demand of customer $l$
$C_{1ij}$	Unit shipping cost of product from $P_i$ to $DC_j$
$C_{2jk}$	Unit shipping cost of product from $DC_j$ to $R_k$
$C_{3kl}$	Unit shipping cost of product from $R_k$ to $C_l$
$C_{4il}$	Unit shipping cost of product from $P_i$ to $C_l$
$C_{5jl}$	Unit shipping cost of product from $DC_j$ to $C_l$
$C_{6ik}$	Unit shipping cost of product from $P_i$ to $R_k$
$u_j^D$	Upper bound of the capacity of $DC_j$
$u_k^R$	Upper bound of the capacity of $R_k$
$f_j^F$	Fixed part of the open cost of $DC_j$
$C_j^{1v}$	Variant part of the open cost (lease cost) of $DC_j$
$q_j^1$	Throughput of $DC_j$
	$q_j^1 = \sum_{i=1}^I X_{1ij}, \forall j$
$f_j$	Open cost of $DC_j$
	$f_j = f_j^F + C_j^{1v} q_j^1, \forall j$
$g_k^F$	Fixed part of the open cost of $R_k$
$C_k^{2v}$	Variant part of the open cost (lease cost) of $DC_j$
$q_k^2$	Throughput of $R_k$
	$q_k^2 = \sum_{l=1}^L X_{3kl}, \forall k$
$g_k$	Open cost of $R_k$
	$g_k = g_k^F + C_k^{2v} q_k^2, \forall k$

**Decision Variables:**

$X_{1ij}$	Product amount shipped from $P_i$ to $DC_j$
$X_{2jk}$	Product amount shipped from $DC_j$ to $R_k$
$X_{3kl}$	Product amount shipped from $R_k$ to $C_l$
$X_{4il}$	Product amount shipped from $P_i$ to $C_l$
$X_{5jl}$	Product amount shipped from $DC_j$ to $C_l$
$X_{6ik}$	Product amount shipped from $P_i$ to $R_k$

$$y_j^1 = \begin{cases} 1, & \text{if } DC_j \text{ is open} \\ 0, & \text{otherwise} \end{cases}$$

$$y_k^2 = \begin{cases} 1, & \text{if } R_k \text{ is open} \\ 0, & \text{otherwise} \end{cases}$$

The objective function is to minimize the total logistic cost  $Z$ . The mathematical model for the fMLN problem is given as follows:

$$\begin{aligned} \text{Min } Z = & \sum_{i=1}^I \sum_{j=1}^J C_{1ij} X_{1ij} + \sum_{j=1}^J \sum_{k=1}^K C_{2jk} X_{2jk} + \sum_{k=1}^K \sum_{l=1}^L C_{3kl} X_{3kl} + \\ & \sum_{i=1}^I \sum_{l=1}^L C_{4il} X_{4il} + \sum_{j=1}^J \sum_{l=1}^L C_{5jl} X_{5jl} + \sum_{i=1}^I \sum_{k=1}^K C_{6ik} X_{6ik} + \sum_{j=1}^J f_j y_j^1 + \sum_{k=1}^K g_k y_k^2 \end{aligned} \quad (1)$$

Subject to:

$$\sum_{j=1}^J X_{1ij} + \sum_{l=1}^L X_{4il} + \sum_{k=1}^K X_{6ik} \leq b_i, \quad \forall i \quad (2)$$

$$\sum_{i=1}^I X_{1ij} = \sum_{k=1}^K X_{2jk} + \sum_{l=1}^L X_{5jl}, \quad \forall j \quad (3)$$

$$\sum_{j=1}^J X_{2jk} + \sum_{i=1}^I X_{6ik} = \sum_{l=1}^L X_{3kl}, \quad \forall k \quad (4)$$

$$\sum_{i=1}^I X_{4il} + \sum_{j=1}^J X_{5jl} + \sum_{k=1}^K X_{3kl} \geq d_l, \quad \forall l \quad (5)$$

$$\sum_{i=1}^I X_{1ij} \leq u_j^D y_j^1, \quad \forall j \quad (6)$$

$$\sum_{l=1}^L X_{3kl} \leq u_k^R y_k^1, \quad \forall k \quad (7)$$

$$X_{1ij}, X_{2jk}, X_{3kl}, X_{4il}, X_{5jl}, X_{6ik} \geq 0, \quad \forall i, j, k, l \quad (8)$$

$$y_j^1, y_k^2 \in \{0, 1\}, \quad \forall j, k \quad (9)$$

Where the objective of function in Eq. 1 means to minimize the total logistic cost, the constraint in Eq.2 represents the production limit of plants. The constraints in Eq.3 and Eq.4 are due to the flow of conservation principle. The constraint in Eq.5 ensures that the customers' demands will be satisfied. The constraints in Eq.6 and Eq.7 ensure that the upper bound of the capacity of DCs and retailers cannot be surpassed.

Although Gen *et al.* (2008) has included assumption 5, that is, every customer is served by only one facility, which leads to a single source fMLN model, and the above formulated model is in fact a multi source fMLN model. This is obvious from the formulated constraint in Eq. (5). This equation represent that each customer can be served by multi facilities (plants, DCs and retailers) simultaneously. A test using LINDO (a software to solve linear programming problem using simplex method) proved that the above formulation is a multi source fMLN model.

### Imperialist competitive algorithm

Evolutionary optimization methods, inspired by natural processes, have shown good performance in solving complex optimization problems. For example, genetic algorithms (inspired by biological evolution of human and other species), ant colony optimization (based on ant efforts to find optimal path to the food source) and simulated annealing (based on real annealing process in which a substance is heated over its melting point and then cooled to reach to a crystalline lattice) are widely used to solve engineering optimization problems.

Evolutionary optimization algorithms are generally inspired by modeling the natural processes and other aspects of evolution, especially of human. But Imperialist Competitive Algorithm (ICA) uses socio-political evolution of human as a source of inspiration for developing a strong optimization strategy. In particular, this algorithm considers imperialism as a level of human social evolution and by mathematically modeling this complicated political and historical process, it arrives at a tool for evolutionary optimization. Since its inception, this

novel method has been widely adopted by researchers to solve different optimization tasks. It is used to design optimal layout of factories, adaptive antenna arrays, intelligent recommender systems and optimal controller for industrial and chemical processes (Atashpaz *et al*, 2007).

Imperialism is the policy of extending the power and rule of a government beyond its own boundaries. A country may attempt to dominate others by direct rule or by less obvious means such as a control of markets for goods or raw materials. The latter is often called neo-colonialism (Atashpaz and Lucas 2007). ICA is a novel global search heuristic that uses imperialism and imperialistic competition process as a source of inspiration. Figure 8 shows the flowchart of the Imperialist Competitive Algorithm (ICA) (Atashpaz and Lucas 2007). Like other evolutionary algorithms, the proposed algorithm starts with an initial population (countries in the world). Some of the strongest countries in the population are selected to be the imperialists and the rest form their colonies. All the colonies of initial population are divided among the imperialists based on their power. The power of an empire seen as the counterpart of the fitness value in Genetic Algorithm (GA) is inversely proportionate to the costs it incurs. After dividing all colonies among imperialists, the colonies start moving towards their relevant master. The total power of an empire depends on both the power of the imperialist country and the power of its colonies. We will model this fact by defining the total power of an empire by the power of imperialist country plus a percentage of mean power of its colonies (Hosseini Nasab, 2010).

Then the imperialistic competition begins among the empires. Any empire that is not able to succeed in this competition and increase its power (or at least prevent decreasing its power) will be eliminated from the competition. The imperialistic competition will gradually result in an increase in the power of powerful empires and a decrease in the power of weaker ones. Weak empires will lose their power and ultimately collapse. The movement of

colonies towards their relevant overlord along with competition among empires and also the collapse mechanism is expected to converge all countries into global monopoly where all the other countries are colonies to one empire (Hosseini Nasab, 2010).

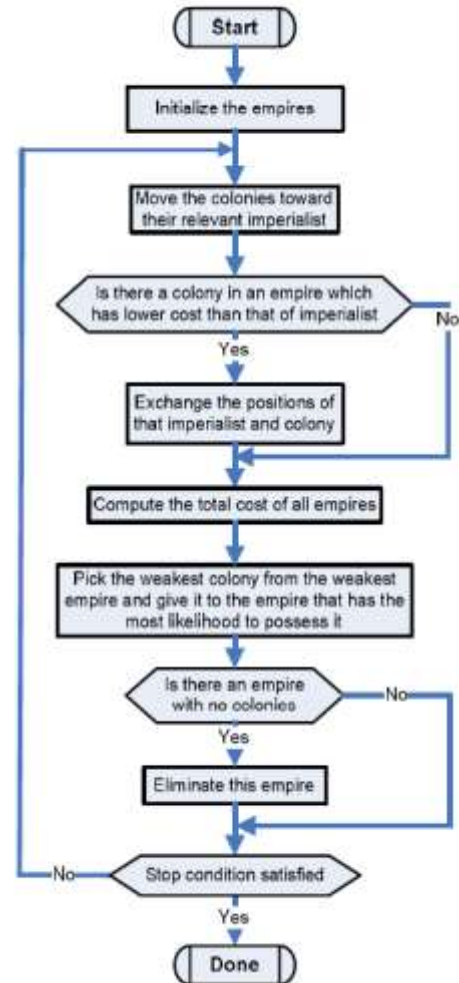


Figure 2: Flowchart of the ICA (Atashpaz *et al*, 2010).



The general picture of Imperialist Competitive Algorithm is shown in Figure 3.

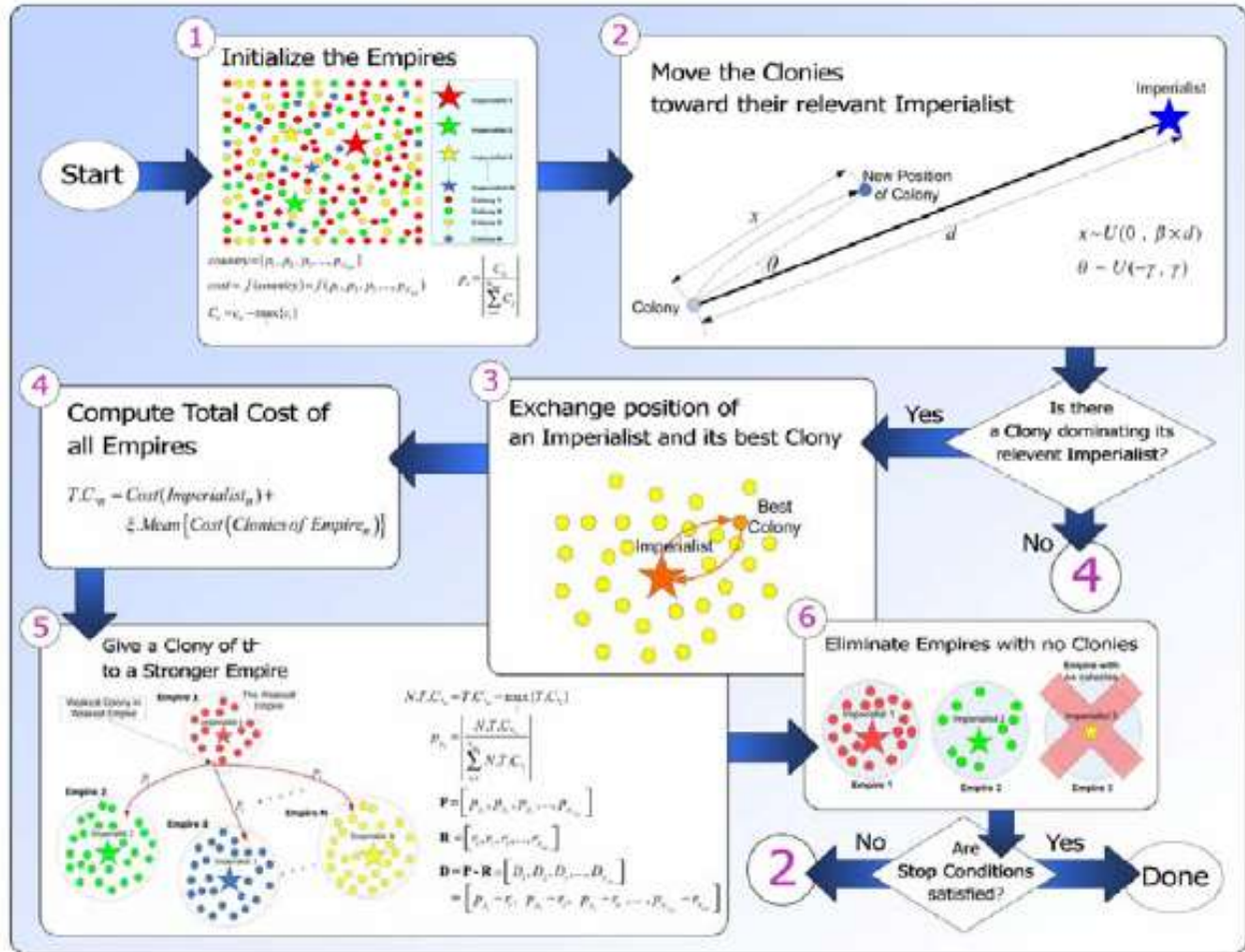


Figure 3: General picture of ICA (Hosseini Nasab, 2010).

**Country representation**

Here, the fully explanation of how the country will be formed in line with solving the flexible logistics network problem is presented. The length of country is  $I*(J+K+L) + J*(K+L) + K*L$  and every cell shows one trait of the country to include culture, education, language...etc.

This paper intend to find the optimal amount of product, considering the cost of product shipment, and the best route for each customer with optimum amount and minimum cost will be find. Indeed, the cost of product shipment of each node in the network is known and according to the constraints of the problem we shall choose the best product delivery

route for each customer satisfied by all existing constraints.

As we know there are six types of shipment in flexible multi-stage logistic network with six decision variables which are  $X_{1ij}, X_{2jk}, X_{3kl}, X_{4il}, X_{5jl}, X_{6ik}$  where the number of X (product amount) varies with the number of plants, DCs, Retailers and customers. For instance if I=2, J=2, K=2 and L=2, then there are 24 decision variables to calculate.

Therefore, the traits of the country are displayed as the product amount of each node at each stage (figure 4).

$I*K$		$I*J$		$J*K$		$K*L$		$I*L$		$J*L$	
$X_{1ij}$	...	$X_{2jk}$	...	$X_{3kl}$	...	$X_{4il}$	...	$X_{5jl}$	...	$X_{6ik}$	...

Figure 4: Country Representation

**Numerical Experiment of ICA**

In this section we show the result of same eight problem cases which already used for GA. Table 1 is depicting the comparison of the elapsed time of ICA and GA in terms of using the same computer and same problem cases. As we mentioned

before the problem assumptions for applying ICA and GA are same, means that for both of them the problem is multi source flexible logistics network. Figure 5 is a three dimensional curve illustrating how the empires attract the colonies from problem number 2.

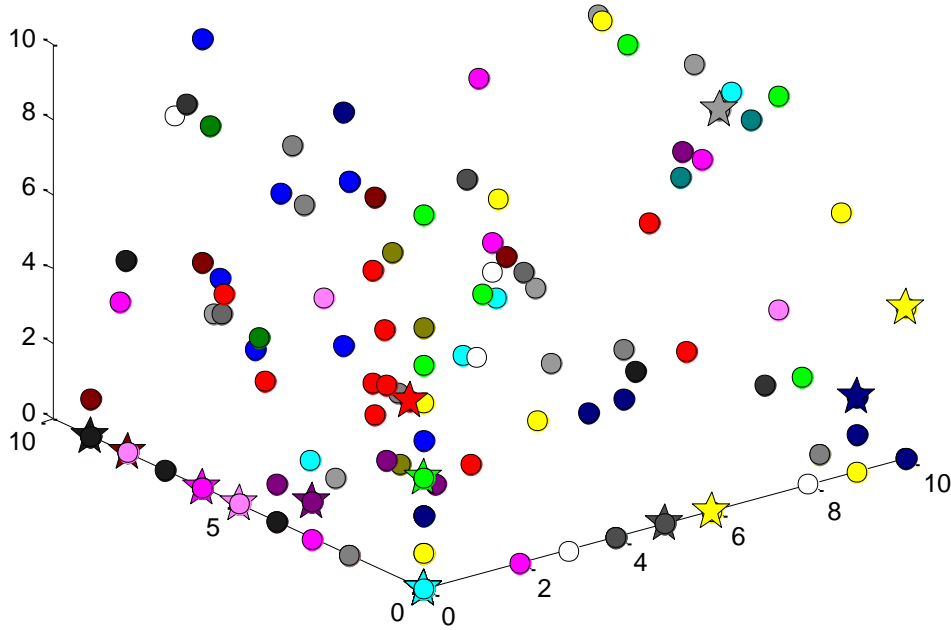


Figure 5: colonization's process

Table 1 Elapsed time comparison of ICA and GA

Problem #	Number of plants	Number of DCs	Number of Retailers	Number of Customers	Number of Decision variables	Number of Constraints	Number of Decades	ICA elapsed Time (s)	GA elapsed Time (s)
1	2	4	7	15	245	28	300	82.41	96.93
2	4	7	10	25	663	46	300	173.51	125.24
3	5	9	12	40	1253	66	400	424.70	236.43
4	7	11	15	60	2327	93	500	704.72	498.33
5	9	13	17	85	3806	124	700	1545.72	820.43
6	10	14	18	100	4772	142	700	2151.68	992.52
7	10	16	19	150	7404	195	900	3378.73	1815.26
8	15	18	22	300	17496	355	1200	6865.85	3776.27

After take a look at table 3 we found that ICA is relevant for small cases in compare with GA, since the ICA is good to solve the multi source flexible multistage logistic problem, but it takes quiet long time, therefore table 3 shows that GA with penalty method is more stranger than ICA to solving the big cases problems.

### Conclusion

The aim of this paper was to optimize the flexible multi-stage logistic network as proposed by some authors. The fMLN is more effective compared to the more traditional ways, because three new delivery routes were introduced here. The mathematical formulation of this model existed and some authors tried to optimize it by various algorithms and methods. This paper addressed the problem of optimization of fMLN considering the multi source network and the optimum product amount and obtaining the best delivery route for each customer based on obtained and reasonable product amount. Since this problem is NP-hard, this research applied Imperialist Competitive Algorithm to solve it. There are a lot of existing constraints here that have to be satisfied before proceedings to calculate the minimum network cost. The comparison result between single source fMLN problem and Multi source fMLN problem and also the comparison result between multi source fMLN problem using GA and multi source fMLN problem using ICA were presented.

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