

Efficiency of a multi-objective imperialist competitive algorithm: A bi-objective location-routing-inventory problem with probabilistic routes

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Abstract

An integrated model considers all parameters and elements of different deficiencies in one problem. This paper presents a new integrated model of a supply chain that simultaneously considers facility location, vehicle routing and inventory control problems as well as their interactions in one problem, called location-routing-inventory (LRI) problem. This model also considers stochastic demands representing the customers' requirement. The customers' uncertain demand follows a normal distribution, in which each distribution center (DC) holds a certain amount of safety stock. In each DC, shortage is not permitted. Furthermore, the routes are not absolutely available all the time. Decisions are made in a multi-period planning horizon. The considered bi-objectives are to minimize the total cost and maximize the probability of delivery to customers. Stochastic availability of routes makes it similar to real-world problems. The presented model is solved by a multi-objective imperialist competitive algorithm (MOICA). Then, well-known multi-objective evolutionary algorithm, namely non-dominated sorting genetic algorithm II (NSGA-II), is used to evaluate the performance of the proposed MOICA. Finally, the conclusion is presented.

Keywords: *Multi-objective Imperialist Competitive Algorithm, Location-routing-inventory Problem, Probabilistic Routes, Multi Periods.*

1. Introduction

In the last decades, industries figured out the effect of integration and coordination in supply chain management, on the superiority between all the competitors. In this competitive surrounding, companies have to increase their efficiency in their logistics' operations because of their economic benefits. In general, an integrated supply chain network comprises three important elements, namely facility location, vehicle routing and inventory control decisions. These elements are highly related and changes on one of them affect deeply on the other one. Much research has concentrated on the integration of two of the above mentioned problems (i.e., location-routing, location-

inventory and inventory-routing problems). Recently, several papers have been published on LRIs; however, there are some areas focusing on have not yet been addressed.

For the first time, Liu and Lee [1] studied a multi-depot, single product location-routing problem with inventory control decisions and proposed a two phase heuristic method to solve the problem. Gaur and Fisher [2] proposed an inventory-routing problem in a supermarket chain; they considered a periodic policy in their problem. Liu and Lin [3] solved the same model of LRI problem, by a combined tabu search and simulated annealing algorithms. The first paper proposed LRI problem

and incorporated ternary integration costs with an approximate routing cost is Shen and Qi [4]. They addressed a single-product, single-period problem and solved the LRI model by a Lagrangian relaxation based solution algorithm, their model was modified inventory–location model given in Daskin et al. [5]. Chanchan et al. [6] formulated a dynamic LRI problem in a closed loop supply chain and solved with a two-phase heuristic algorithm. In another research, Ahmadi Javid and Azad [7] developed the model presented by [4]. Their model simultaneously optimizes location, inventory and routing decisions without approximation, and solved by a hybrid tabu search and simulated annealing methods. Hiassat and Diabat [8] studied the LRI problem with perishable products through a single commodity, multi-period model. Bard and Nananukul [9] suggested a periodic inventory routing problem, in a specific time period furthermore backlogging is not permitted. They solved their model by a branch-and-price method. Abdelmaguid et al. [10] studied a multi-period inventory routing problem that shortage is permitted and solved by a developed constructive and improvement heuristics and obtained the solutions approximately.

Recently Ahmadi Javid and Seddighi [11] extended the earlier work to a location-routing-inventory model with a multi-source distribution network. Their model considers the LRI model in a three-level distribution network and a multiphase heuristic algorithm based on simulated annealing (SA) and ant colony system (ACS). Lee and Chang [12], however, reported on solving discrete location problems when the facilities are prone to failure. They assumed that the facilities, such as fire station, emergency shelter, service center, telecommunication post, and distribution center would not provide services for whatever reason, such as maintenance, capacity limit, breakdown, or shutdown of unknown causes. Hwang [13,14] considered that the probability of a depot warehouse center is known. Hwang [13] developed stochastic set-covering location models for both ameliorating and deteriorating items. Hassanpour et al. [15] presented a new model of stochastic location-routing problem that facilities and routes are available with the probability and applied a two phase heuristic method to solve the problem.

In this paper, we introduce an efficient bi-objective model for LRI problem. In this multi-period model,

the routes are available with probability of an interval $(0, 1)$. In this condition, routes are not available or they are available along with risk. Examples might include crisis condition (e.g., natural disaster).

2. Problem description and formulation

In this paper, we focus on the LRI problem of a two-echelon logistic distribution system, which consist of customers and DCs. The model locates several DCs from a set of potential DCs and allocates customers to them.

The associated model determines routes of vehicles to satisfy the customers' demand and optimal inventory policy through periods of planning horizon. The objective of this model is to minimize the total cost and the probability of delivery to customers. Assumptions made in this study are given below.

2.1. Assumptions

The following assumptions are considered in the presented model.

1. There is a 2-echelon distribution system.
2. There are some distribution centers (DCs) for supplying customers.
3. The LRI problem is multi-period one.
4. Each customer has an uncertain non-negative demand that is independent and follows a normal distribution that must be satisfied in each time period.
5. In each DC j , the (Q_{jt}, R_{jt}) inventory policy is applied. In this policy, when the inventory level in period t at distribution center j gets to or below a reorder point R_{jt} , a fixed quantity Q_{jt} is ordered to the supplier. Also, each distribution center holds amount of safety stock in each period.
6. Locating and allocating decisions are made in strategic level and are not related to periods.
7. The transportation cost includes traveling distance related cost and vehicle fixed cost for determining usage of vehicle v .
8. Vehicle fleet is heterogeneous.
9. Shortage is not permitted.
10. Availability of routes is assumed to be probabilistic nature.

The following notation is used in the formulation of the proposed model.

Table 1. Sets.

Symbol	Description
K and L	Set of customers
J	Set of potential distribution centers
N_j	Set of capacity levels available to distribution center $j(j \in J)$
V	Set of vehicles
M	Aggregate set of customers and potential distribution centers ($k \cup j$)
T	Set of periods along time horizon

Table 2. Parameters.

Symbol	Description
μ_{kt}	Mean of customer k demand in period $t (\forall k \in K, \forall t \in T)$
δ_{kt}^2	Variance of customer k demand in period $t (\forall k \in K, \forall t \in T)$
f_j	Establishing cost of DC $j (\forall j \in J, \forall n \in N_j)$
L_j	Capacity level for DC $j (\forall j \in J, \forall n \in N_j)$
d_{kl}	Transportation cost for traveling from node k to node $l (\forall k, l \in M)$
V_v	Maximum capacity of vehicle $v (\forall v \in V)$
K	Number of visits of each customer in a year
H_{jt}	Inventory holding cost in period t at DC $j (\forall j \in J, \forall t \in T)$
C_j	Fixed ordering cost to supplier by DC $j (\forall j \in J)$
L_{jt}	Lead time of DC j in period $t (\forall j \in J, \forall t \in T)$
g_j	Fixed shipping cost for transferring products from supplier to DC j per shipment ($\forall j \in J$)
a_j	Shipment cost for transferring from supplier to DC $j (\forall j \in J)$
B	Number of customers contained in set K , (i.e., $B = K $)
Pr_v	Fixed usage cost of vehicle $v (\forall v \in V)$
P_{kl}	availability of path between arc k and l in time period $t (\forall k, l \in M, t \in T)$
α	Level of service for customer orders that should be satisfied
Z_α	Standard normal deviate such that $P(z \leq z_\alpha) = \alpha$
β	Weight factor associated with transportation cost
θ	Weight factor associated with the inventory cost
q_{kl}	$1 - P_{kl}$

Decision variables

$$X_{klvt} = \begin{cases} 1 & \text{if } k \text{ precedes } l \text{ in a route of vehicle } v \text{ in period } t \\ 0 & \text{otherwise} \end{cases}$$

$(\forall k, l \in M, v \in V, t \in T)$

$$Y_{jk} = \begin{cases} 1 & \text{if customer } k \text{ is assigned to distribution center } j \\ 0 & \text{otherwise} \end{cases}$$

$(\forall j \in J, \forall k \in K)$

$$U_j = \begin{cases} 1 & \text{if distribution center } j \text{ is open} \\ 0 & \text{otherwise} \end{cases}$$

$(\forall j \in J, \forall n \in N_j)$

$$M_{kvt}$$
 Sub-tour elimination variable for customer k in route of vehicle v in period t
 $(\forall k \in K, \forall v \in V, \forall t \in T)$

2.2. Mathematical model

$$f_1 = \min \sum_{j \in J} f_j U_j + \beta K \left(\sum_{v \in V} \sum_{k \in M} \sum_{l \in M} \sum_{t \in T} d_{kl} X_{klvt} + \sum_{j \in J} \sum_{v \in V} \sum_{t \in T} Pr_v X_{jvlt} + \right. \tag{1}$$

$$\left. \sum_{j \in J} \left[\sqrt{2\theta \sum_{k \in K} \sum_{t \in T} h_{jt} (\theta C_j + \beta g_j) \mu_{kt} Y_{jk}^2} + \beta \sum_{t \in T} a_j \sum_{k \in K} \mu_{kt} Y_{jk}^2 + \theta \sum_{t \in T} h_{jt} z_\alpha \sqrt{L_{jt} \sum_{k \in K} \delta_{kt}^2 Y_{jk}^2} \right] \right]$$

$$f_2 = \max \sum_{v \in V} \sum_{t \in T} \left(\prod_{k \in K} \prod_{l \in L} P_{kl} X_{klvt} \right) \tag{2}$$

s.t.

$$\sum_{v \in V} \sum_{l \in M} X_{klvt} = 1 \quad \forall t \in T \quad \forall k \in K \quad (3)$$

$$\sum_{l \in K} \mu_{lt} \sum_{k \in M} X_{klvt} \leq V_v \quad \forall t \in T, \forall v \in V \quad (4)$$

$$M_{kvt} - M_{lvt} + (B \times X_{klvt}) \leq B - 1 \quad \forall t \in T \quad \forall k, l \in K, \forall v \in V \quad (5)$$

$$\sum_{l \in M} X_{klvt} - \sum_{l \in M} X_{lkvt} = 0 \quad \forall t \in T \quad \forall k \in M, \forall v \in V \quad (6)$$

$$\sum_{j \in J} \sum_{k \in K} X_{jkvt} \leq 1 \quad \forall t \in T, \forall v \in V \quad (7)$$

$$\sum_{l \in M} X_{klvt} + \sum_{l \in M} X_{jlvt} - Y_{jk} \leq 1 \quad \forall t \in T, \forall j \in J, \forall k \in K, \forall v \in V \quad (8)$$

$$\sum_{k \in K} \mu_{kt} Y_{jk} \leq L_j U_j \quad \forall t \in T, \forall j \in J \quad (9)$$

$$\sum_{j \in J} Y_{jk} = 1 \quad \forall k \in K \quad (10)$$

$$Y_{jk} \in \{0,1\} \quad \forall j \in J, \forall k \in K \quad (11)$$

$$U_j \in \{0,1\} \quad \forall j \in J \quad (12)$$

$$X_{klvt} \in \{0,1\} \quad \forall t \in T, \forall k, l \in M, \forall v \in V \quad (13)$$

$$M_{kvt} \text{ free variable} \quad \forall k \in K, \forall v \in V, \forall t \in T \quad (14)$$

Objective function (1) minimizing total costs consists of locating allocating, vehicle routing and inventory control costs. Objective function (2) maximizes the probability of delivery to customers. Equation (3) ensures that each customer can serve at most one vehicle (route) in each time period. Equation (4) is the vehicle capacity constraint and bound the total delivery to each customer in each period of time. Equation (5) ensures sub-tour elimination.

Equation (6) guarantees route continuity. Equation (7) ensures that a rout contains a distribution center node in a time period. Equation (8) states that a customer can be allocated to a distribution center in each period of time only if there is a route passed by that customer and originated from that distribution center.

Equation (9) is distribution center capacity constraint. Equation (10) states that each customer can be assigned to only one distribution center over a planning horizon. Equation (11) to (14) are the domain constraints on variables.

2.3. Interpretation of the second part of the objective function

Multiplication of objective function (2) can be changed to summation and from the minimum to

the maximum. In this objective function, the probability P_{klt} is between (0, 1) and variable X_{klvt} is zero or one. To solve this problem, maximizing $f_2=f(x)$ is equivalent to the maximization of $f_3 = f_2+A$.

$$f_3 = \max \sum_{t \in T} \sum_{v \in V} \left(\prod_{k \in K} \prod_{l \in L} (P_{klt} X_{klvt} + 1 - X_{klvt}) \right) \quad (13)$$

So we will have:

$$P_{klt} X_{klvt} + 1 - X_{klvt} = \begin{cases} 1, & X_{klvt} = 0 \\ P_{klt}, & X_{klvt} = 1 \end{cases} \quad (14)$$

Instead of maximizing f_3 , we can maximize $f_4 = \text{Ln}(f_3)$:

$$f_4 = \text{Ln} \left\{ \max \sum_{t \in T} \sum_{v \in V} \left(\prod_{k \in K} \prod_{l \in L} (P_{klt} X_{klvt} + 1 - X_{klvt}) \right) \right\} \quad (15)$$

Or,

$$f_4 = \max \sum_{t \in T} \sum_{v \in V} \text{Ln} \left(\prod_{k \in K} \prod_{l \in L} (P_{klt} X_{klvt} + 1 - X_{klvt}) \right) \quad (16)$$

By applying Ln to f_4 , the multiplication will be changed to the summation.

$$f_4 = \max \sum_{t \in T} \sum_{v \in V} \sum_{k \in K} \sum_{l \in L} (P_{klt} X_{klvt} + 1 - X_{klvt}) \quad (17)$$

For convincing the optimization problem, we multiply f_4 by -1.

$$f_5 = -\min \sum_{t \in T} \sum_{v \in V} \sum_{k \in K} \sum_{l \in L} (P_{klt} X_{klvt} + 1 - X_{klvt}) \quad (18)$$

Or,

$$f_5 = \min \sum_{t \in T} \sum_{v \in V} \sum_{k \in K} \sum_{l \in L} (-P_{klt} X_{klvt} - 1 + X_{klvt}) \quad (19)$$

By replacement of $P_{klt}=1-q_{klt}$, we have:

$$f_5 = \min \sum_{t \in T} \sum_{v \in V} \sum_{k \in K} \sum_{l \in L} (-(1-q_{klt}) X_{klvt} - 1 + X_{klvt}) \quad (20)$$

$$f_5 = \min \sum_{t \in T} \sum_{v \in V} \sum_{k \in K} \sum_{l \in L} (q_{klt} X_{klvt} - A) \quad (21)$$

By eliminating the constant part, f_5 will be changed to f_6 as follows:

$$f_6 = \min \sum_{t \in T} \sum_{v \in V} \sum_{k \in K} \sum_{l \in L} q_{klt} X_{klvt} \quad (22)$$

After applying changes, the first and second objective functions are (1) and (22), respectively.

3. Proposed algorithm

Location-routing-inventory problem is NP-hardness [7]. In this paper, a multi-objective imperialist competitive algorithm (MOICA) is proposed to solve the multi-objective model. Additionally, we presents NSGA-II (non-dominated sorting genetic algorithm II) to compare the numerical results generated by the proposed MOICA.

3.1. Multi-objective imperialist competitive algorithm

A multi-objective imperialist competitive algorithm (MOICA) is a multi-objective meta-heuristic evolutionary algorithm inspired by the human social evolution for its optimization strategy [16].

The MOICA methodology, in the first step, produces initial solution as countries. After generating countries, a non-dominance technique and a crowding distance are used to rank and select the population fronts and the members of front one are saved in an archive. To calculate the cost value of each imperialist the normalized cost value of each imperialist

($Cost_n$) is calculated by the summation of the normalized value of the i -th objective function as shown below:

$$Cost_n = \sum_{i=1}^r Cost_{i,n} \quad (23)$$

The best solutions are selected as the imperialists and the remaining countries are considered as

colonies. The total power of an empire is mostly influenced by the power of the imperialist country not by the power of the colonies of an empire. This power is calculated by:

$$TP \text{ of } Emp_n = Total \text{ Cost}(Imperialist_n) + \xi mean\{Total \text{ Cost}(Colonies \text{ of } Empire_n)\} \quad (24)$$

Imperialists made their colonies to move toward themselves along different axis by assimilation function. Afterward, colonies share their information between themselves by crossover operation and then each imperialism affects by mutation operation.

In the imperialistic competition, gradually the power of the stronger emprise will increase and the power of the weaker emprise will reduce, in which the strongest imperialists picking colonies of other less powerful imperialists and the powerless empires will eliminate. The stopping criteria of the imperialistic competition are remaining just one emperor. The pseudo code of the proposed MOICA is presented in figure 1.

3.2. Non-dominated sorting genetic algorithm II

The non-dominated sorting genetic algorithm II (NSGA-II) [19] applies a non-dominance technique and a crowding distance to rank and select the population fronts. The crossover and mutation operators are used to produce new solutions. The current populations and new generated populations are combined together and the best solutions are selected by means of non-dominance and crowding distance.

Non-dominance technique: A multi-objective model has n objective functions, solution x_1 and x_2 are placed in the same front when do not dominate each other, in which x_1 dominate x_2 if:

1. For all the objective functions, solution x_1 is not worse than another solution x_2 .
2. For at least one of the n objective functions, x_1 is absolutely better than x_2 .

Front 1 is made of all solutions that are not dominated by any other solutions. Front number 2 encompasses all solutions that only dominated by solutions in front number 1.

Crowding distance: It approximates the density of solutions surrounding a specific solution. Having lower value of crowding distance are preferred over another solutions.

Tournament selection operator: This process includes both the crossover and mutation operators.

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NFC (number of function calls) ← 0
set the parameters of MOICA ( $n$ -Pop,  $N$ -imp,  $\zeta, \beta$ ,  $P$ -Assimilation,  $P$ -Crossover,  $P$ -Revolution,  $n$ -Archive)
Generate the initial countries (Randomly) ←  $n$ -Pop
Evaluate fitness of each country
update the NFC
Form the initial empires:
    a) Choose most powerful countries as the imperialists ←  $N$ -imp
    b) Assign other countries to imperialists based on imperialist power ( $pop1$ )
terminate ← false
while (terminate = false) do at each Imperialist
    Move the colonies of an empire toward the imperialist ( $pop2$ ) ←  $P$ -Assimilation ( $P_A$ ),  $\beta$ 
    Crossover some colonies with empire ( $pop3$ ) ←  $P$ -Crossover ( $P_C$ )
    Revolution among colonies ( $pop4$ ) ←  $P$ -Revolution ( $P_R$ )
    Evaluate fitness of each country
    Update the NFC
    Merge all created population
    Update colonies
    Update archive ←  $n$ -Archive
    if (Cost of colony is lower than its own Empire) then
        Exchange the positions of the imperialist and a colony
    end
    Calculate the total power of the empires ←  $\zeta$ 
    Perform imperialistic competition
    Eliminate the powerless empires (the imperialist with no colony)
    if (NFC = predefined value) then
        terminate = true
    end if
end while

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Figure 1. Pseudo code of the proposed MOICA.

At first, in this method, two solutions of the population size are selected. If the two populations selected are from same front, the solution with the highest crowding distance is selected and if they become from the different fronts, the lowest front number is selected.

4. Computational results

In this section, the performance of the proposed MOICA and NSGA-II, which discussed in the previous section, is compared with each other.

4.1. Comparison metric

To validate the proposed MOICA, we propose two comparison metrics, namely quality metric (QM) and spacing metric (SM).

The QM method gathers the non-dominated solutions obtained by algorithms and computes the portion of the Pareto solution of each algorithm. Higher value of this metric shows a higher performance for the solutions of this metric [17]. The SM method computes the uniformity of the extension of the non-dominated set solutions [18].

$$SM = \frac{\sum_{i=1}^{n-1} |\bar{d} - d_i|}{(n-1)\bar{d}} \quad (25)$$

Where d_i is the Euclidean distance between seriate solutions in the obtained non-dominated set of solutions and \bar{d} is the average of that. As the value of this metric reduces the uniformity increases and shows the higher performance of algorithms.

4.2. Comparison of meta-heuristic solution methods

In this section, we carry out two set of experiments to evaluate the performance of two proposed meta-heuristic algorithms according to two suggested comparison metrics.

Tables 3 and 4 consist of solving 15 test problems with MOICA and NSGA-II based on the QM and the SM, respectively.

In these tables, we illustrate the summary of numerical result associated with the problems designed above and tested through using NSGA-II and MOICA.

We report that the proposed MOICA is more efficient than the NSGA-II in all 15 test problems.

Table 3. Comparison results between the NSGA-II and MOICA according to the QM.

Problem No.	Period No.	Customer No.	DC No.	Vehicle No.	NSGA-II	MOICA
1	3	10	5	3	0.07	0.9
2	3	15	5	3	0.2	0.65
3	3	30	5	3	0.05	0.81
4	5	50	5	3	0.03	0.88
5	5	70	5	3	0.09	0.75
6	5	100	5	3	0	0.98
7	7	10	5	3	0.09	0.85
8	7	15	5	3	0.01	0.75
9	7	30	5	3	0.25	0.7
10	3	50	5	3	0.2	0.9
11	3	70	10	4	0	0.66
12	3	100	10	4	0.01	0.78
13	5	10	5	3	0	0.93
14	5	15	10	4	0.12	0.65
15	5	30	10	4	0.16	0.82

Table 4. Comparison results between the NSGA-II and MOICA according to the SM.

Problem No.	Period No.	Customer No.	DC No.	Vehicle No.	NSGA-II	MOICA
1	3	10	5	3	0.68	0.454
2	3	15	5	3	0.41	0.345
3	3	30	5	3	0.553	0.385
4	5	50	5	3	0.598	0.473
5	5	70	5	3	0.659	0.445
6	5	100	5	3	0.559	0.382
7	7	10	5	3	0.559	0.27
8	7	15	5	3	0.598	0.335
9	7	30	5	3	0.79	0.483
10	3	50	5	3	0.86	0.26
11	3	70	10	4	0.554	0.568
12	3	100	10	4	0.92	0.509
13	5	10	5	3	0.884	0.405
14	5	15	10	4	0.624	0.466
15	5	30	10	4	0.77	0.404

5. Conclusion

In this paper, we have outlined a formulation of bi-objective location-routing-inventory problem. The model shows how the customers allocate to the opened DCs, how a vehicle selects routes to serve the customer demands in each period and the frequency to reorder at a DC and what level of safety stock to maintain. The objective functions minimize the total costs and maximize the probability of delivery to customers. We presented two multi-objective meta-heuristic solution

approaches namely, NSGA-II and MOICA. We have solved 15 test problems with these two meta-heuristics. The results have shown that the proposed MOICA has been more efficient than the proposed NSGA-II based on two proposed comparison metrics, namely quality and space metrics. The considered problem can be developed to a closed-loop supply chain by adding some reverse logistic system assumptions. Furthermore, developing other

meta-heuristics for the given problem is an interesting future research direction.

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عملکرد الگوریتم رقابت استعماری چند هدفه: یک مسئله مکان‌یابی - مسیریابی - موجودی چند هدفه با مسیره‌های احتمالی

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چکیده:

یک مدل یکپارچه مدلی است که همه‌ی پارامترها و عناصر مختلف را در یک مسئله در نظر بگیرد. این مقاله، یک مدل یکپارچه جدید از یک زنجیره‌ی تأمین را ارائه می‌دهد که به صورت همزمان سه مسئله‌ی مکان‌یابی تجهیزات، مسیریابی وسیله نقلیه، کنترل موجودی انبار و اثرات متقابل آن‌ها بر روی یکدیگر را در نظر می‌گیرد و مسئله‌ی مکان‌یابی - مسیریابی - موجودی نامیده می‌شود. همچنین این مدل تقاضاهای مشتریان را به صورت احتمالی در نظر می‌گیرد که این تقاضای نامشخص از یک توزیع نرمال پیروی می‌کند و هر مرکز توزیع یک مقداری موجودی اطمینان را نگهداری می‌کند، کمبود در مراکز توزیع مجاز نمی‌باشد، به علاوه مسیره‌ها همیشه در دسترس نیستند. تصمیمات در یک افق برنامه ریزی چند دوره ای گرفته شده‌اند. دو هدف در نظر گرفته شده، هزینه‌ی کل را کمینه و احتمال تحویل به مشتریان را بیشینه می‌کنند. در دسترس بودن احتمالی مسیره‌ها مدل را به مسائل جهان واقعی شبیه تر می‌کند. مدل ارائه شده با یک الگوریتم رقابت استعماری چند هدفه حل شده است، سپس یک الگوریتم تکاملی چند هدفه معروف به نام NSGA-II برای ارزیابی عملکرد الگوریتم MOICA ارائه شده استفاده شده است. در نهایت، نتیجه‌گیری ارائه می‌شود.

کلمات کلیدی: الگوریتم رقابت استعماری چند هدفه، مسئله مکان‌یابی - مسیریابی - موجودی، مسیره‌های احتمالی، چند دوره ای.