Spektrum Industri
Vol. 22, No. 2, 2024, pp. 155-162
ISSN 1693-6590
http://journal3.uad.ac.id/index.php/spektrum

Tabu Search Algorithm for Solving a Location-Routing-Inventory Problem

Nova Indah Saragih [a,*], Peri Turnip [b]

[a] Department of Industrial Engineering, Telkom University, Bandung, 40257, Indonesia
[b] Department of Mathematics, International Women University, Bandung, 40173, Indonesia
* Corresponding Author: novaindah@telkomuniversity.ac.id

ARTICLE INFO

Article history
Received June 22, 2024
Revised September 26, 2024
Accepted October 23, 2024

Keywords
Location decision;
Vehicle routing;
Inventory control;
Tabu search

ABSTRACT

Location decisions, inventory control, and vehicle routing are interrelated decisions. Inventory control decisions, such as order lot size and order frequency, affect both inventory and transportation costs. Failure to take inventory and transportation costs into consideration when determining location decisions can lead to suboptimality since they have a large impact on inventory and transportation costs. Therefore, how to decide locations, determine vehicle routing, and control inventory optimally, or location-routing-inventory problem (LRIP), becomes an important issue to design logistics systems. The objective of this paper is to develop a heuristic method base on Tabu Search (TS) to solve a LRIP. The contribution of this paper which is the heuristic method based on TS to solve a LRIP has never been developed before. TS is a type of metaheuristic. The success of TS is due to its ability to direct the search process so as not to get trapped in the local optimum, in large part, like many other metaheuristics. The result of the computational comparison show that the heuristic method can provide a relatively small average gap of 3.20% in terms of total cost compared to the optimal method. Application of the proposed heuristic is done in DKI Jakarta.

1. Introduction

Location decisions, inventory control, and vehicle routing are interrelated decisions (Liu & Lin, 2005). The decisions of inventory control, such as order frequency and order lot size, affect both transportation and inventory costs. For example, small quantity and frequent shipments often result in reduced inventory costs but require additional transportation costs (Liu & Lee, 2003) (Leuveano et al., 2023). Furthermore, routing and inventory control decisions affect location decisions because they are determined based on minimum system cost criteria (Liu & Lin, 2005) (Asih et al., 2022). Failure to take inventory and transportation costs into consideration when determining location decisions can lead to suboptimality since they have a large impact on inventory and transportation costs (Max Shen & Qi, 2007). A study conducted by (N. Saragih et al., 2017) showed that integration model of location decisions, inventory control, and vehicle routing resulted smaller system costs compared to decomposition model. Therefore, how to decide locations, determine vehicle routing, and control inventory optimally, or location-routing-inventory problem (LRIP), becomes an important issue to design logistics systems.

Developing a heuristic method to solve a LRIP based on Tabu Search is the purpose of this paper. The supply chain system consists of multi retail markets, multi UCCs (urban consolidation centers), and single supplier. The problems addressed are how to decide the location of UCCs, to allocate retail markets to opened UCCs, to control inventory in all entities involved in the supply chain, and to determine the vehicle routes from opened UCCs to retail markets such that the total cost is minimized. Retail markets' demand is single product, probabilistic, and follows a normal distribution. Application of the proposed heuristic is done in DKI Jakarta to design a new logistics system.

In the last 10 years, works have been done related to LRIP (Table 1). (Nekooghadirli et al., 2014) developed algorithm of multi-objective meta-heuristic to solve a LRIP. The LRIP considered multi products, probabilistic demands, and multi echelons. (Zhang et al., 2014) solved a LRIP using local search and simulated annealing. The LRIP considered single product, deterministic demand, and multi echelons. (Tang et al., 2016) used multi-objective particle swarm optimization to solve a LRIP considering single product, probabilistic demand, and multi echelons. (Ghorbani & Akbari Jokar, 2016) used simulated annealing and imperialist competitive to solve a LRIP. The LRIP considered multi products, probabilistic demands, and multi echelons.

(Zhalechian et al., 2016) used self-adaptive genetic algorithm and variable neighbourhood search to solve a LRIP considering multi products, probabilistic demands, and multi echelons. (Hiassat et al., 2017) used genetic algorithm to solve a LRIP considering single product, deterministic demands, and single echelon. (Rayat et al., 2017) used archived multi-objective simulated annealing to solve a LRIP considering multi products, deterministic demands, and multi echelons. (Rafie-Majd et al., 2018) used Lagrangian relaxation algorithm to solve LRIP considering multi products, deterministic demands, and multi echelons. (Vahdani et al., 2018) used non-dominated sorting genetic algorithm II and multi-objective particle swarm optimization to solve LRIP considering multi products, probabilistic demands, and multi echelons. (N. I. Saragih et al., 2019) used simulated annealing to solve a LRIP considering single product, probabilistic demand, and multi echelons. (Bagherinejad & Najafi-Ghobadi, 2019) used evolutionary simulated annealing and genetic algorithms to solve a LRIP considering single product, deterministic demand, and multi echelons.

(Farias et al., 2020) proposed two-phase heuristic and Branch-and-Cut algorithm to solve a LRIP considering single product, deterministic demand, and multi echelons. (Rahbari et al., 2020) proposed general algebraic modelling system to solve a LRIP considering single product, deterministic demand, and multi echelons. (Karakostas et al., 2020) used general variable neighborhood search to solve a LRIP considering single product, deterministic demand, and single echelon. (N. Saragih et al., 2021) used simulated annealing to solve a LRIP considering multi products, deterministic demands, and multi echelons. (Wu et al., 2021) proposed a two-stage hybrid metaheuristic algorithm, which was genetic algorithm and a gradient descent algorithm, to solve a LRIP. The problem considered single product, deterministic demand, and multi echelons. (N. Saragih et al., 2022) solved a LRIP using simulated annealing. The LRIP considered multi products, probabilistic demands, and multi echelons. (Tavana et al., 2023) solved a LRIP using a Lagrangian relaxation algorithm. The problem considered multi products, probabilistic demands, and multi echelons. As it can be seen from Table 1, the contribution of this paper which is the heuristic method to solve a LRIP based on Tabu Search has never been developed before.

2. Method

2.1. Tabu Search Algorithm

Fig. 1 gives the proposed heuristic based of Tabu Search (TS) algorithm. (Glover, 1989) described, introduced, and refined TS. TS is a type of metaheuristic. The success of TS is largely due to its ability to direct the search process so that it does not get trapped in a local optimum, like many other metaheuristics. This is achieved by allowing moves to neighboring solutions that can result in a decrease in the objective value but simultaneously avoid re-cycling through the previous step. To solve complex combinatorial optimization problems, TS has been widely used.

Table 1. Works Related to LIRP

Works	Decisions of inventory			Number of echelons	
	Customers/ Retailers	UCCs/ Distribution centers/ Warehouses	Supplier/ Plants	Single	Multi
This work	√	√	√		√
(Tavana et al., 2023)	√				√
(N. Saragih et al., 2022)	√	√	√		√
(Wu et al., 2021)	√	√			√
(N. Saragih et al., 2021)	√	√	√		√
(Karakostas et al., 2020)	√			√	
(Rahbari et al., 2020)	√	√	√		√
(Farias et al., 2020)	√	√	√		√
(N. I. Saragih et al., 2019)	√	√	√		√
(Bagherinejad & Najafi-Ghobadi, 2019)	√	√		√	
(Vahdani et al., 2018)		√		√	
(Rafie-Majd et al., 2018)	√				√
(Hiassat et al., 2017)	√			√	
(Rayat et al., 2017)		√			√
(Zhalechian et al., 2016)		√			√
(Tang et al., 2016)		√			√
(Ghorbani & Akbari Jokar, 2016)	√	√			√
(Nekooghadirli et al., 2014)		√			√
(Zhang et al., 2014)	√				√

The TS procedure exploits short-term memory, namely the Tabu List (TL). TL keeps track of recently visited solutions (their attributes). Moving to a neighboring solution is allowed if the neighboring solution is not in the Tabu List (TL) or has identical attributes (e.g. goal value) to the solution in that list. However, although prohibited by the TL, the move to a neighboring solution can be chosen based on several aspiration criteria. The model of LRIP solved by the TS algorithm in this paper can be seen in (N. I. Saragih et al., 2019).

The notations of the proposed heuristic are given as follows: IS_0 is the initial solution, $CS_{current}$ is the current solution, BS_{best} is the best solution, and $tabu_{max}$ is the maximum size of TL. Fig. 2 shows the pseudo code of the proposed algorithm.

3. Results and Discussion

3.1. Computational Experiments

To evaluate the solution of the Tabu Search method that has been developed, a comparison of the objective function value and computational time is carried out against the optimal method solution resulted by LINGO 12.0. The comparison is made on eleven numerical examples (Table 2). Based on the value of the objective function, the gap between the heuristic method solution and the optimal method solution is calculated. The gap is calculated by:

Gap (%) = 100 × (the value of the objective function of the heuristic method – the value of the objective function of the optimal method) / the value of the solution of the optimal method

The data used to evaluate the proposed heuristic are generated based on (N. I. Saragih et al., 2019). Meanwhile, the parameters of TS for the proposed heuristic are given as follows: n_{max} is 200, l_{max} is 100, and $tabu_{max}$ is 10.

The result of the computational comparison show that the heuristic method can provide a relatively small average gap of 3.20% in terms of total cost compared to the optimal method.

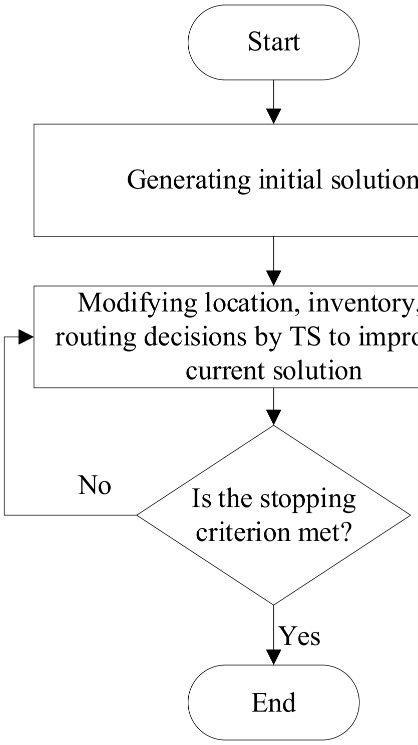

Fig. 1. The Proposed Algorithm

```
Take IS_0
Set the TS parameters n_max, l_max, tabu_max
Initial CS_current = IS_0, BS_best = IS_0, TL = 0, n = 1, l = 1
For n = n: n_max
    For l = l: l_max
        CS_current =mov1(CS_current)
        CS_current =mov2(CS_current)
        CS_current =mov3(CS_current)
        CS_current =mov4(CS_current)
        If CS_current is non-tabu solution
            If CS_current meets all the constraints
                value = evaluate (CS_current)
                If (value < BS_best)
                    BS_best = value
                End If
            If TL size > tabu_max
            Remove the old TL
            End If
            Update TL
            End If
        End If
    End For
End For
```

Fig. 2. The Pseudo Code of the Proposed Algorithm

Table 2. Comparison of the Solutions

No.	#Tradition-al markets	#UCC	Optimal Method		Tabu Search		Gap (%)
			Total cost	CPU time (s)	Total cost	CPU time (s)	Total cost
1	3	2	411.06*	112	415.27	2.38	1.02
2	4	2	534.73*	436	537.23	2.40	0.47
3	5	2	751.10**	43200	759.46	2.24	1.11
4	6	2	874.69**	43200	967.74	4.97	10.64
5	7	2	966.52**	43200	1015.95	4.69	5.11
6	3	3	406.27*	356	406.27	2.90	0.00
7	4	3	538.47**	43200	591.00	3.01	9.76
8	5	3	797.23**	43200	789.46	2.98	-0.97
9	6	3	877.21**	43200	892.18	8.51	1.71
10	7	3	NA	NA	1113.56	8.69	NA
11	8	3	NA	NA	1231.82	8.10	NA
		(*) Global optimal (**) Local optimal				Average	3.20

3.2. Application of Tabu Search Algorithm

The Tabu Search method developed is then applied to the real system in DKI Jakarta. Using the Google Earth application, the location of the Retail Market and UCC can be seen in Fig. 3.

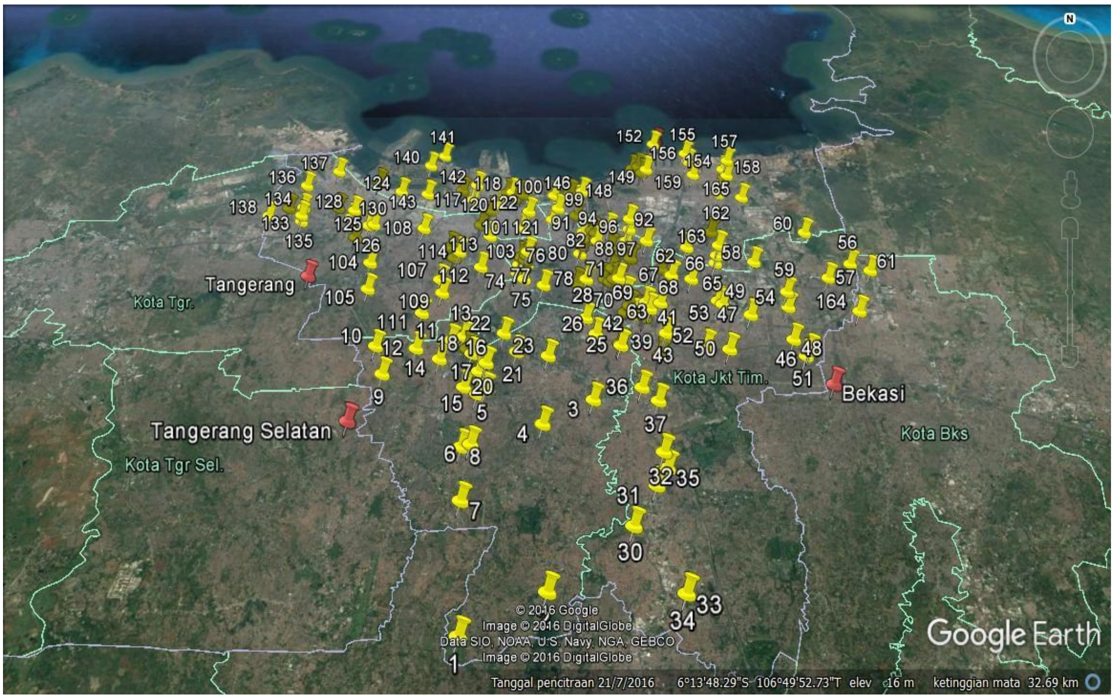

Fig. 3. Retail Markets and UCCs Location Map

There are 165 retail markets, 4 potential UCCs, and 1 supplier in the real system of DKI Jakarta. The data are taken from (N. I. Saragih et al., 2019). The retail markets are spread throughout DKI Jakarta, of which 42 retail markets are located in East Jakarta, 36 retail markets are located in West Jakarta, 32 retail markets are located in Central Jakarta, and 26 retail markets located are in North Jakarta, 29 retail markets are located in South Jakarta. The potential UCCs are located in Jakarta – Tangerang Toll Road Area, Jakarta – Serpong Toll Road Area, Jakarta – Cikampek Toll Road Area, and Port of Tanjung Priok. Table 3 shows the solution for the Tabu Search method for the retail markets. Table 4 shows the solution for the Tabu Search method for UCC. Table 5 shows the solution for the Tabu Search method for suppliers.

Table 3. Retail Market Solutions

Retail markets	Demand (Kg/day)	Number of shortage (Kg)	Safety Stock (Kg)	Lot size (Kg)	Order frequency
1	211	0.62	15	84.63	1
2	211	0.65	16	84.63	1
3	174	0.54	13	69.78	1
4	174	0.55	13	69.78	1
5	57	0.18	4	22.91	1
6	57	0.17	4	22.91	1
7	57	0.17	4	22.91	1
8	57	0.18	4	22.91	1
9	127	0.35	8	50.77	1
10	127	0.42	10	50.77	1
11	88	0.26	6	35.13	1
12	88	0.26	6	35.13	1
13	88	0.26	6	35.13	1
14	88	0.24	6	35.13	1
15	21	0.06	1	8.25	1
16	21	0.06	1	8.25	1
17	21	0.07	2	8.25	1
18	21	0.06	2	8.25	1
19	21	0.06	1	8.25	1
20	21	0.06	1	8.25	1
21	21	0.06	1	8.25	1
22	21	0.06	1	8.25	1
23	343	1.14	27	137.44	1
24	60	0.18	4	24.26	1
25	60	0.20	5	24.26	1
26	60	0.20	5	24.26	1
27	60	0.20	5	24.26	1
28	79	0.24	6	31.80	1
29	79	0.26	6	31.80	1
30	239	0.73	18	95.85	1

Table 4. UCC Solutions

UCC	Demand of UCC (Kg/day)	Lot size UCC (Kg)	Vehicle capacity (Kg)	Order frequency
4	11,657	4,663	800	1

Table 5. Supplier Solutions

Supplier	*T* (Day)	*T* (Hour)	Demand	Lot Size (Kg)	Truck capacity (Kg)
1	0.4	10	11,657	4,663	8,000

As it shows in Table 4, selected UCC is UCC 4 which is Port of Tanjung Priok. In the selected UCC, consolidation and coordination functions are carried out related to the distribution of loads from the UCC to retail markets, vehicle routes from selected UCC to retail markets, and inventory control at supplier, UCC, and retail markets. The new design of logistics system in DKI Jakarta is also able to reduce vehicles' number due to the use of the same vehicles in UCC. In addition, with the presence of UCC in DKI Jakarta, the development of other initiatives will also be opened. And example is the use of environmentally friendly vehicles or green vehicles in UCC to send the goods to retail markets. So, the new design of logistics system is efficient and it also does not add DKI Jakarta's transportation problem which is traffic congestion.

4. Conclusion

This study has succeeded in developing a heuristic method for solving a LRIP based on Tabu Search. Application of the proposed heuristic is done in DKI Jakarta. The results of the computational comparison show that the heuristic method can provide a relatively small average gap of 3.20% in terms of total cost compared to the optimal method. For future work, considering heterogeneous fleet and time windows can be interesting topics. Identifying the effective values of parameters used in the hybrid heuristic can be an interesting topic as well, since in this paper, they are given. Developing other metaheuristics such as Genetic Algorithm, Ant Colony, or hybrid ones can be interesting topics as well. Study related to the implementation of the new design of logistics system in DKI Jakarta can be a suggestion for future work.

Author Contribution: This paper is contributed by all authors equally. The final paper is read and approved by all authors.

Funding: Telkom University funded this research trough the grant of Penelitian Dasar dan Terapan.

Conflicts of Interest: No conflict of interest is declared.

References

Asih, H. M., Leuveano, R. a. C., Rahman, A., & Faishal, M. (2022). Traveling Salesman Problem With Prioritization For Perishable Products In Yogyakarta, Indonesia. *Journal of Advanced Manufacturing Technology (JAMT)*, *16*(3), https://jamt.utem.edu.my/jamt/article/view/6405.

Bagherinejad, J., & Najafi-Ghobadi, S. (2019). Two Meta-heuristic Algorithms for a Capacitated Inventory-location Problem in Multi-echelon Supply Chain. *International Journal of Supply and Operations Management*, *6*(4), 334–348, https://doi.org/10.22034/2019.4.4.

Farias, K., Hadj-Hamou, K., & Yugma, C. (2020). Model and exact solution for a two-echelon inventory routing problem. *International Journal of Production Research*, *0*(0), 1–24, https://doi.org/10.1080/00207543.2020.1746428.

Ghorbani, A., & Akbari Jokar, M. R. (2016). A hybrid imperialist competitive-simulated annealing algorithm for a multisource multi-product location-routing-inventory problem. *Computers and Industrial Engineering*, *101*, 116–127, https://doi.org/10.1016/j.cie.2016.08.027.

Glover, F. (1989). Tabu Search—Part I. *ORSA Journal on Computing*, *1*(3), 190–206, https://doi.org/10.1287/ijoc.1.3.190.

Hiassat, A., Diabat, A., & Rahwan, I. (2017). A genetic algorithm approach for location-inventory-routing problem with perishable products. *Journal of Manufacturing Systems*, *42*, 93–103, https://doi.org/10.1016/j.jmsy.2016.10.004.

Karakostas, P., Sifaleras, A., & Georgiadis, M. C. (2020). Adaptive variable neighborhood search solution methods for the fleet size and mix pollution location-inventory-routing problem. *Expert Systems with Applications*, *153*, 113444, https://doi.org/10.1016/j.eswa.2020.113444.

Leuveano, R. A. C., Asih, H. M., Ridho, M. I., & Darmawan, D. A. (2023). Balancing Inventory Management: Genetic Algorithm Optimization for A Novel Dynamic Lot Sizing Model in Perishable Product Manufacturing. *Journal of Robotics and Control (JRC)*, *4*(6), Article 6, https://doi.org/10.18196/jrc.v4i6.20667.

Liu, S. C., & Lee, S. B. (2003). A two-phase heuristic method for the multi-depot location routing problem taking inventory control decisions into consideration. *The International Journal of Advanced Manufacturing Technology*, *22*(11), 941–950, https://doi.org/10.1007/s00170-003-1639-5.

Liu, S. C., & Lin, C. C. (2005). A heuristic method for the combined location routing and inventory problem. *The International Journal of Advanced Manufacturing Technology*, *26*(4), 372–381, https://doi.org/10.1007/s00170-003-2005-3.

Max Shen, Z.-J., & Qi, L. (2007). Incorporating inventory and routing costs in strategic location models. *European Journal of Operational Research*, *179*(2), 372–389, https://doi.org/10.1016/j.ejor.2006.03.032.

Nekooghadirli, N., Tavakkoli-Moghaddam, R., Ghezavati, V. R., & Javanmard, S. (2014). Solving a new bi-objective location-routing-inventory problem in a distribution network by meta-heuristics. *Computers and Industrial Engineering*, *76*(1), 204–221, https://doi.org/10.1016/j.cie.2014.08.004.

Rafie-Majd, Z., Pasandideh, S. H. R., & Naderi, B. (2018). Modelling and solving the integrated inventory-location-routing problem in a multi-period and multi-perishable product supply chain with uncertainty: Lagrangian relaxation algorithm. *Computers and Chemical Engineering*, *109*, 9–22, https://doi.org/10.1016/j.compchemeng.2017.10.013.

Rahbari, M., Razavi Hajiagha, S. H., Raeei Dehaghi, M., Moallem, M., & Riahi Dorcheh, F. (2020). Modeling and solving a five-echelon location–inventory–routing problem for red meat supply chain: Case study in Iran. *Kybernetes*, *ahead-of-print*(ahead-of-print), https://doi.org/10.1108/K-10-2019-0652.

Rayat, F., Musavi, M. M., & Bozorgi-Amiri, A. (2017). Bi-objective reliable location-inventory-routing problem with partial backordering under disruption risks: A modified AMOSA approach. *Applied Soft Computing Journal*, *59*, 622–643, https://doi.org/10.1016/j.asoc.2017.06.036.

Saragih, N., Bahagia, S. N., Suprayogi, S., & Syabri, I. (2017). Model Integrasi Keputusan Lokasi, Perutean Kendaraan, dan Pengendalian Persediaan Pada Sistem Rantai Pasok Tiga Eselon. *Jurnal Teknik Industri*, *19*(1), Article 1, https://doi.org/10.9744/jti.19.1.1-10.

Saragih, N., Bahagia, S., Suprayogi, S., & Syabri, I. (2021). Location-inventory-routing model with considering urban road networks. *Journal of Industrial Engineering and Management*, *14*(4), Article 4, https://doi.org/10.3926/jiem.3557.

Saragih, N. I., Bahagia, S. N., Suprayogi, & Syabri, I. (2019). A heuristic method for location-inventory-routing problem in a three-echelon supply chain system. *Computers and Industrial Engineering*, *127*, https://doi.org/10.1016/j.cie.2018.11.026.

Saragih, N., Nur Bahagia, S., Suprayogi, S., & Syabri, I. (2022). Location-inventory-routing Problem in a Context of City Logistics: A Case Study of Jakarta. *Operations and Supply Chain Management: An International Journal*, *15*(2), 218–227, https://doi.org/10.31387/oscm0490342.

Tang, J., Ji, S., & Jiang, L. (2016). The design of a sustainable location-routing-inventory model considering consumer environmental behavior. *Sustainability (Switzerland)*, *8*(3), https://doi.org/10.3390/su8030211.

Tavana, M., Khalili Nasr, A., Santos-Arteaga, F. J., Saberi, E., & Mina, H. (2023). An optimization model with a lagrangian relaxation algorithm for artificial internet of things-enabled sustainable circular supply chain networks. *Annals of Operations Research*, https://doi.org/10.1007/s10479-023-05219-3.

Vahdani, B., Veysmoradi, D., Noori, F., & Mansour, F. (2018). Two-stage multi-objective location-routing-inventory model for humanitarian logistics network design under uncertainty. *International Journal of Disaster Risk Reduction*, *27*(October 2017), 290–306, https://doi.org/10.1016/j.ijdrr.2017.10.015.

Wu, W., Zhou, W., Lin, Y., Xie, Y., & Jin, W. (2021). A hybrid metaheuristic algorithm for location inventory routing problem with time windows and fuel consumption. *Expert Systems with Applications*, *166*, 114034, https://doi.org/10.1016/j.eswa.2020.114034.

Zhalechian, M., Tavakkoli-Moghaddam, R., Zahiri, B., & Mohammadi, M. (2016). Sustainable design of a closed-loop location-routing-inventory supply chain network under mixed uncertainty. *Transportation Research Part E: Logistics and Transportation Review*, *89*, 182–214, https://doi.org/10.1016/j.tre.2016.02.011.

Zhang, Y., Qi, M., Miao, L., & Liu, E. (2014). Hybrid metaheuristic solutions to inventory location routing problem. *Transportation Research Part E: Logistics and Transportation Review*, *70*(1), 305–323, https://doi.org/10.1016/j.tre.2014.07.010.