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Article

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Journal of Industrial Engineering and Management (JIEM)

Provided in Cooperation with:

The School of Industrial, Aerospace and Audiovisual Engineering of Terrassa (ESEIAAT),
Universitat Politècnica de Catalunya (UPC)

Suggested Citation: Saragih, Nova Indah; Bahagia, Senator Nur; Suprayogi, Suprayogi; Syabri, Ibnu (2021) : Location-inventory-routing model with considering urban road networks, Journal of Industrial Engineering and Management (JIEM), ISSN 2013-0953, OmniaScience, Barcelona, Vol. 14, Iss. 4, pp. 830-849,
<https://doi.org/10.3926/jiem.3557>

This Version is available at:

<https://hdl.handle.net/10419/261782>

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Location-Inventory-Routing Model with Considering Urban Road Networks

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Received: April 2021

Accepted: September 2021

Abstract:

Purpose: To develop LIRP (location-inventory-routing problem) model with considering multiple links and solve it using method of heuristic based on algorithm of simulated annealing. Method of heuristic for the LIRP model is applied in city of Jakarta to improve effectiveness and efficiency of the food supply chain.

Design/methodology/approach: The LIRP model is developed using main references. To solve the model, this paper develops two methods, namely method of optimal and method of heuristic. Computational experiments are performed to obtain the efficiency of the method of heuristic. New design of food supply chain is resulted from the application of the method of heuristic in city of Jakarta.

Findings: The new design of food supply chain resulted from the application of LIRP model in city of Jakarta reduces total cost by 18%, increases availability from 76% to 95%, and reduces the number of vehicles by 73%. This paper also shows that distance is not the only consideration to decide the traversed links in cities.

Research limitations/implications: Average gap between method of heuristic and method of optimal in terms of total cost is 3.1%.

Practical implications: Government of city of Jakarta can improve effectiveness and efficiency of the food supply chain by implementing the LIRP model.

Social implications: Citizens of Jakarta are well provided with their needs of vegetables and fruits.

Originality/value: The first LIRP model that considers multiple links to represent road networks in cities. The LIRP model developed in this paper consists of probabilistic demands, multi products, and multi echelons. Traditional markets, UCCs (urban consolidation centers) and province of suppliers are the places where decisions of inventory made.

Keywords: LIRP model, cost of congestion, road networks, method of heuristic, simulated annealing

To cite this article:

Saragih, N.I., Bahagia, S.N., Suprayogi, S., & Syabri, I. (2021). Location-inventory-routing model with considering urban road networks. *Journal of Industrial Engineering and Management*, 14(4), 830-849. <https://doi.org/10.3926/jiem.3557>

1. Introduction

There are multiple road networks that connect places in urban areas. To apply the model of LIRP (location-inventory-routing problem) in urban areas, one needs to consider multiple links to represent the road networks. There is no model of LIRP that considers multiple links. It can be known from literature review of LIRP that has been done in Table 1; therefore, there is a research gap that needs to address related to this issue. To solve the model, this paper develops two methods, namely method of optimal and method of heuristic. The method of heuristic is developed based on algorithm of simulated annealing and is applied in city of Jakarta to design a new supply chain for food and improve the effectiveness and efficiency.

In the last 10 years, here are papers related to LIRP model. Sajjadi and Cheraghi (2011) developed LIRP model and solved it using simulated annealing. The model consisted of probabilistic demands, multi products, and multi echelons. Depots and customers were the places where decisions of inventory made. Guerrero, Prodhon, Velasco and Amaya (2013) developed LIRP model and solved it using local search and algorithm of randomized extended Clarke and Wright. The model consisted of deterministic demand, single product, and single echelon. In Guerrero et al. (2013), depots and customers were the places where decisions of inventory made. Nekooghadrli, Tavakkoli-Moghaddam, Ghezavati and Javanmard (2014) developed LIRP model and solved it using algorithm of multi-objective meta-heuristic. The model consisted of probabilistic demands, multi products, and multi echelons. Distribution centers were the places where decisions of inventory made. Zhang, Qi, Miao and Liu (2014) developed LIRP model where customers were the places where decisions of inventory made. Zhang et al. (2014) solved the model using simulated annealing and local search. The model consisted of deterministic demand, single product, and multi echelons.

Tang, Ji and Jiang (2016) developed LIRP model and solved it using multi-objective particle swarm optimization. Warehouses were the places where decisions of inventory made. The model in Tang et al. (2016) consisted of probabilistic demand, single product, and multi echelons. Ghorbani & Akbari-Jokar (2016) developed LIRP model and solved it using imperialist competitive and simulated annealing. The model consisted of probabilistic demands, multi products, and multi echelons. Depots and customers were the places where decisions of inventory made. Zhalechian, Tavakkoli-Moghaddam, Zahiri and Mohammadi (2016) developed LIRP model and solved it using variable neighborhood search and self-adaptive genetic algorithm. The model consisted of probabilistic demands, multi products, and multi echelons. Distribution centers were the places where decisions of inventory made. Hiassat, Diabat and Rahwan (2017) developed LIRP model that consisted of deterministic demands, single product, and single echelon. The model solved using genetic algorithm. Customers were the places where decisions of inventory made. Rayat, Musavi and Bozorgi-Amiri (2017) developed LIRP model and solved it using archived multi-objective simulated annealing. Distribution centers were the places where decisions of inventory made. The model consisted of deterministic demands, multi products, and multi echelons.

Rafie-Majd, Pasandideh and Naderi (2018) developed LIRP model that consisted of deterministic demands, multi products, and multi echelons. The model was solved using algorithm of Lagrangian relaxation. Customers were the places where decisions of inventory made. Vahdani, Veysmoradi, Noori and Mansour (2018) developed LIRP model and solved it using multi-objective particle swarm optimization and non-dominated sorting genetic algorithm II. The model consisted of probabilistic demands, multi products, and multi echelons. Distribution centers/warehouses were the places where decisions of inventory made. Saragih, Bahagia, Suprayogi and Syabri (2019) developed LIRP model and solved it using simulated annealing. The model consisted of probabilistic demand, single product, and multi echelons. Retailers, depots and supplier were the places where decisions of inventory made. Bagherinejad & Najafi-Ghobadi (2019) developed LIRP model and solved it using genetic algorithm and algorithm of evolutionary simulated annealing. The model consisted of deterministic demand, single product, and multi echelons. Retailers and warehouses were the places where decisions of inventory made.

Farias, Hadj-Hamou and Yugma (2020) developed LIRP model and solved it using algorithm of Branch-and-Cut and two-phase heuristic. The model consisted of deterministic demand, single product, and multi echelons. Customers, distribution centers, and supplier were the places where decisions of inventory made. Rahbari,

Razavi-Hajiagha, Raaei-Dehaghi, Moallem and Riahi-Dorcheh (2020) developed LIRP model that consisted of deterministic demand, single product, and multi echelons. The model was solved using general algebraic modeling system. Decisions of inventory made at all entities. Karakostas, Sifaleras and Georgiadis (2020) developed LIRP model and solved it using general variable neighbourhood search. The model consisted of deterministic demand, single product, and single echelon.

Papers	Number of products		Decisions of inventory			Number of echelons		Number of links		Heuristic methods
	Single	Multi	Customers/ Retailers	Depots/ Distribution centers/ Warehouses	Suppliers/ Plants	Single	Multi	Single	Multi	
Sajjadi & Cheraghi (2011)		√	√	√			√	√		Simulated annealing
Guerrero et al. (2013)	√		√	√		√		√		Local search and algorithm of randomized extended Clarke and Wright
Nekooghadirli et al. (2014)		√		√			√	√		Algorithm of multi-objective meta-heuristic
Zhang et al. (2014)	√		√				√	√		Simulated annealing and local search
Tang et al. (2016)	√			√			√	√		Multi-objective particle swarm optimization
Ghorbani & Akbari-Jokar (2016)		√	√	√			√	√		Imperialist competitive and simulated annealing
Zhalechian et al. (2016)		√		√			√	√		Variable neighbourhood search and self-adaptive genetic algorithm
Hiassat et al. (2017)	√		√			√		√		Genetic algorithm
Rayat et al. (2017)		√		√			√	√		Archived multi-objective simulated annealing
Rafie-Majd et al. (2018)		√	√				√	√		Algorithm of Lagrangian relaxation
Vahdani et al. (2018)		√		√		√		√		Multi-objective particle swarm optimization and non-dominated sorting genetic algorithm II
Saragih et al. (2019)	√		√	√	√		√	√		Simulated annealing
Bagherinejad & Najafi-Ghobadi (2019)	√		√	√		√		√		Genetic algorithm and algorithm of evolutionary simulated annealing

Papers	Number of products		Decisions of inventory			Number of echelons		Number of links		Heuristic methods
	Single	Multi	Customers/ Retailers	Depots/ Distribution centers/ Warehouses	Suppliers/ Plants	Single	Multi	Single	Multi	
Farias et al. (2020)	√		√	√	√		√	√		Branch-and-Cut and two-phase heuristic
Rahbari et al. (2020)	√		√	√	√		√	√		General algebraic modeling system
Karakostas et al. (2020)	√		√			√		√		General variable neighborhood search
This paper		√	√	√	√		√		√	Simulated annealing

Table 1. Papers in LIRP model

The LIRP model developed in this paper consists of probabilistic demands, multi products, and multi echelons. Traditional markets, UCCs (urban consolidation centers) and province of suppliers are the places where decisions of inventory made. UCCs are logistics facilities where consolidation and coordination activities are performed (Saragih et al., 2015). As for the main contribution, this paper considers multiple links to represent the road networks in urban areas, such as the city of Jakarta. The model developed in this paper represents more realistic real systems where there are multiple road networks that connect places in urban areas. From Table 1, this model of LIRP has never been done before. This paper fills the gap by developing the LIRP model.

2. Methodology

To develop the LIRP model, this paper uses Saragih et al. (2018) and Taniguchi, Noritake, Yamada and Izumitani (1999) as the references. Saragih et al. (2018) only considered one link or road to connect two locations in the LIRP model, whereas in urban areas, two locations can be connected by more than one link. This weakness is improved using Taniguchi et al. (1999). The approach used to develop the LIRP model in this paper can be seen in Figure 1.

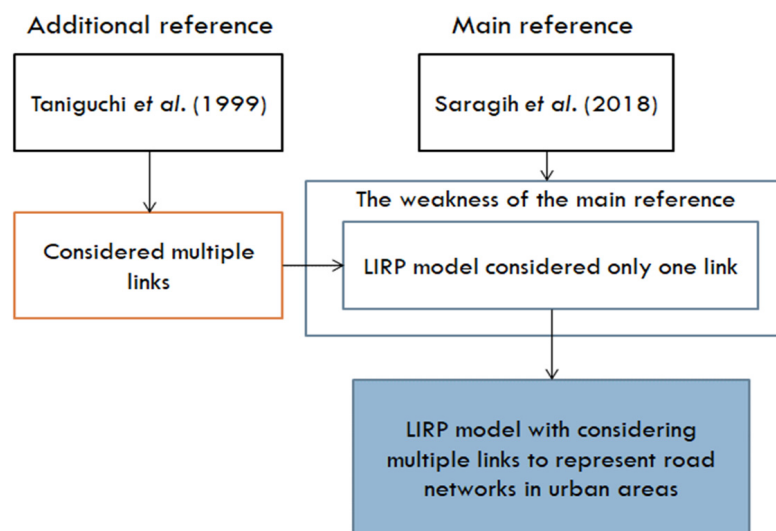


Figure 1. The approach for the development of the model

The illustration of system studied can be seen in Figure 2. Figure 2 consists of two province of suppliers, two UCCs, four traditional markets (TMs), and two links. Link 1 is the green line and link 2 is the blue line.

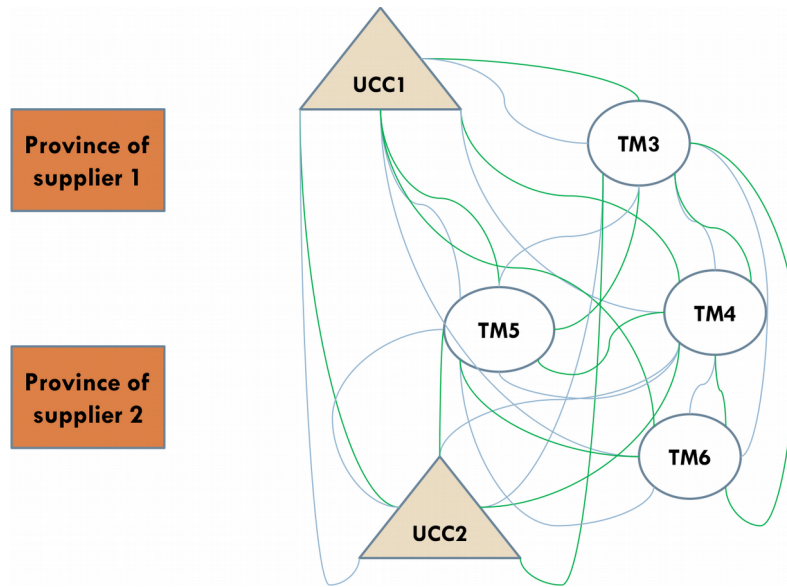


Figure 2. The illustration of system studied

3. Development of Model

The LIRP model developed in this paper is described as follows.

Index sets	
K	set of traditional markets
J	set of potential UCCs
N_j	set of capacity levels available to UCC ($j \in J$)
I	set of province of suppliers
P	set of products
V	set of vehicles
M	merged set of traditional markets and potential UCCs, i.e. $(K \cup J)$
O_{kl}	set of links between node k and node $(l \in M)$

Index	
k	index of traditional markets
j	index of UCCs
n	index of capacity levels available to UCC
i	index of province of suppliers
p	index of products
v	index of vehicles
o	index of links

Parameters and notations	
μ_{kp}	mean of demand at traditional market k for product p (kg/day) ($\forall k \in K, \forall p \in P$)
σ^2_{kp}	variance of demand at traditional market k for product p (kg^2/day^2) ($\forall k \in K, \forall p \in P$)
h_{kp}	inventory holding cost at traditional market k for product p (Rp/kg/day) ($\forall k \in K, \forall p \in P$)
a_{kp}	ordering cost at traditional market k for product p (Rp/order) ($\forall k \in K, \forall p \in P$)
l_{kp}	lead time of traditional market k for product p (day) ($\forall k \in K, \forall p \in P$)
s_{kp}	shortage cost at traditional market k for product p (Rp/kg) ($\forall k \in K, \forall p \in P$)
α	service level for traditional market
z_α	standard normal deviate such that $P(Z \leq z_\alpha) = \alpha$
$f(z_\alpha)$	ordinate of z_α
$\psi(z_\alpha)$	partial expectations of z_α
f_j^n	fixed cost for opening and operating UCC j with capacity level n (Rp/day) ($\forall j \in J, \forall n \in N$)
b_j^n	capacity with level n for UCC j (kg/day) ($\forall j \in J, \forall n \in N$)
d_{kl}	distance between node k and node l (km)
t_{kl}	time loss between node k and node l (hour)
ca	transportation cost (Rp/km)
cb	value of time (Rp/hour)
h_{jp}	inventory holding cost at UCC j for product p (Rp/kg/day) ($\forall j \in J, \forall p \in P$)
a_{jp}	ordering cost at UCC j for product p (Rp/order) ($\forall j \in J, \forall p \in P$)
l_{jp}	lead time of UCC j for product p (day) ($\forall j \in J, \forall p \in P$)
vc	capacity of vehicle (kg)
h_{ip}	inventory holding cost at province of supplier i for product p (Rp/kg/day) ($\forall i \in I, \forall p \in P$)
a_{ip}	ordering cost at province of supplier i for product p (Rp/order) ($\forall i \in I, \forall p \in P$)
l_{ip}	lead time of province of supplier i for product p (day) ($\forall i \in I, \forall p \in P$)
b_{ip}	capacity for province of supplier i for product p (kg/day) ($\forall i \in I, \forall p \in P$)
w	transportation cost of truck (Rp/truck)
pp	capacity of truck (kg)
B	number of customers contained in set K , i.e., $B = K $
TC	total cost (Rp/day)
T	single cycle time (day)

Decision variables	
NP_{kp}	order frequency of traditional market k for product p ($\forall k \in K, \forall p \in P$)
E	order frequency of every traditional market and product
Q_{kp}	lot size of traditional market k for product p (kg) ($\forall k \in K, \forall p \in P$)
Q_k	total lot size of traditional market k (kg)
MK_{kp}	number of shortage at traditional market k for product p (Unit) ($\forall k \in K, \forall p \in P$)

RK_{kp}	reorder point at traditional market k for product p (Unit) ($\forall k \in K, \forall p \in P$)
SS_{kp}	safety stock at traditional market k for product p (Unit) ($\forall k \in K, \forall p \in P$)
M_{kv}	auxiliary variable defined for traditional market k for subtour elimination in route of vehicle v ($\forall k \in K, \forall v \in V$)
U_j^n	$\begin{cases} 1 & \text{if UCC } j \text{ is opened with capacity level } n \\ 0 & \text{otherwise} \end{cases} \quad (\forall j \in J, \forall n \in N)$
Y_{jk}	$\begin{cases} 1 & \text{if traditional market } k \text{ is assigned to UCC } j \\ 0 & \text{otherwise} \end{cases} \quad (\forall j \in J, \forall k \in K)$
R_{klv}^o	$\begin{cases} 1 & \text{if } k \text{ precedes } l \text{ in route of vehicle } v \text{ on link } o \\ 0 & \text{otherwise} \end{cases} \quad (\forall k, l \in M, \forall v \in V, o \in O_{kl})$
D_{jp}	demand of UCC j for product p (kg/day) ($\forall j \in J, \forall p \in P$)
NP_{jp}	order frequency of UCC j for product p ($\forall j \in J, \forall p \in P$)
Z	order frequency of every UCC and product
Q_{jp}	lot size of UCC j for product p (kg) ($\forall j \in J, \forall p \in P$)
Q_j	total lot size of UCC j (kg)
RK_{jp}	reorder point at UCC j for product p (kg) ($\forall j \in J, \forall p \in P$)
X_j	number of truck at UCC j (Truck) ($\forall j \in J$)
G_{ijp}	$\begin{cases} 1 & \text{if province of supplier } i \text{ supplies UCC } j \text{ for product } p \\ 0 & \text{otherwise} \end{cases} \quad (\forall i \in I, \forall j \in J, \forall p \in P)$
D_{ip}	demand of province of supplier i for product p (kg/day) ($\forall i \in I, \forall p \in P$)
Q_{ip}	lot size of province of supplier i for product p (kg) ($\forall i \in I, \forall p \in P$)
Q_i	total lot size of province of supplier i (kg) ($\forall i \in I$)
RK_{ip}	reorder point at province of supplier i for product p (kg) ($\forall i \in I, \forall p \in P$)
X_i	number of truck at province of supplier i (truck) ($\forall i \in I$)
V_{ijp}	amount of demand of UCC i for product p supplied by province of supplier i ($\forall i \in I, \forall j \in J, \forall p \in P$)

3.1. The LIRP Model

The costs consist of:

1. The fixed cost of locating the opened UCCs, given as
$$\sum_{j \in J} \sum_{n \in N_j} f_j^n U_j^n$$
2. The routing cost from the opened UCCs to the traditional markets, given as
$$\frac{E}{T} \sum_{v \in V} \sum_{o \in O_{kl}} \sum_{k \in M} \sum_{l \in M} (d_{kl}^o ca + t_{kl}^o cb) R_{klv}^o$$
3. The expected inventory cost in traditional markets, given as
$$\sum_{k \in K} \sum_{p \in P} \left[\frac{a_{kp} \mu_{kp}}{Q_{kp}} + h_{kp} \left(\frac{Q_{kp}}{2} + SS_{kp} \right) + s_{kp} MK_{kp} \left(\frac{\mu_{kp}}{Q_{kp}} \right) \right]$$
4. The expected inventory cost in UCCs, given as
$$\sum_{j \in J} \sum_{p \in P} \left[\frac{a_{jp} D_{jp}}{Q_{jp}} + h_{jp} \left(\frac{Q_{jp}}{2} + \sum_k (lt_{kp} \mu_{kp} + SS_{kp}) Y_{jk} \right) + w X_j \frac{Z}{T} \right]$$

5. The expected inventory cost in province of suppliers, given as

$$\sum_{i \in I} \sum_{p \in P} \left[\frac{a_{ip} D_{ip}}{Q_{ip}} h_{ip} \left(\frac{Q_{ip}}{2} + \left(\sum_j \sum_k \left((l_{jp} + l_{kp}) \mu_{kp} + SS_{kp} \right) Y_{jk} \right) G_{ijp} \right) + w X_i \frac{1}{T} \right]$$

Objective function:

$$\begin{aligned} \min TC = & \sum_{j \in J} \sum_{n \in N_j} f_j^n U_j^n + \frac{E}{T} \sum_{v \in V} \sum_{o \in O_{kl}} \sum_{k \in M} \sum_{l \in M} (d_{kl}^o ca + t_{kl}^o cb) R_{klv}^o + \\ & \sum_{k \in K} \sum_{p \in P} \left[\frac{a_{kp} \mu_{kp}}{Q_{kp}} + h_{kp} \left(\frac{Q_{kp}}{2} + SS_{kp} \right) + S_{kp} MK_{kp} \left(\frac{\mu_{kp}}{Q_{kp}} \right) \right] + \sum_{j \in J} \sum_{p \in P} \left[\frac{a_{jp} D_{jp}}{Q_{jp}} + h_{jp} \left(\frac{Q_{jp}}{2} + \right. \right. \\ & \left. \left. \sum_k (l_{kp} \mu_{kp} + SS_{kp}) Y_{jk} \right) + w X_j \frac{Z}{T} \right] + \sum_{i \in I} \sum_{p \in P} \left[\frac{a_{ip} D_{ip}}{Q_{ip}} + h_{ip} \left(\frac{Q_{ip}}{2} + \left(\sum_j \sum_k \left((l_{jp} + \right. \right. \right. \right. \\ & \left. \left. \left. \left. l_{kp} \right) \mu_{kp} + SS_{kp} \right) Y_{jk} \right) G_{ijp} \right) + w X_i \frac{1}{T} \right] \end{aligned} \tag{1}$$

Subject to:

$$\sum_{v \in V} \sum_{o \in O_{kl}} \sum_{l \in M} R_{klv}^o = 1, \forall k \in K \tag{2}$$

$$\sum_{o \in O_{kl}} \sum_{l \in K} \sum_{k \in M} Q_l R_{klv}^o \leq vc, \forall v \in V \tag{3}$$

$$M_{kv} - M_{lv} + (B \times R_{klv}^o) \leq B - 1, \forall k, l \in K, \forall o \in O_{kl}, \forall v \in V \tag{4}$$

$$\sum_{o \in O_{kl}} \sum_{l \in M} R_{klv}^o - \sum_{o \in O_{kl}} \sum_{l \in M} R_{klv}^o = 0, \forall k \in M, \forall v \in V \tag{5}$$

$$\sum_{o \in O_{kl}} \sum_{j \in J} \sum_{k \in K} R_{klv}^o \leq 1, \forall v \in V \tag{6}$$

$$\sum_{o \in O_{kl}} \sum_{l \in M} R_{klv}^o + \sum_{o \in O_{kl}} \sum_{l \in M} R_{klv}^o - Y_{jk} \leq 1, \forall j \in J, \forall k \in K, \forall v \in V \tag{7}$$

$$\sum_{o \in O_{kl}} R_{klv}^o \leq 1, \forall v \in V, \forall k, l \in M \tag{8}$$

$$\sum_{n \in N_j} U_j^n \leq 1, \forall j \in J \tag{9}$$

$$\sum_{k \in K} \sum_{p \in P} \mu_{kp} Y_{jk} \leq \sum_{n \in N_j} b_j^n U_j^n, \forall j \in J \tag{10}$$

$$\sum_{k \in K} \mu_{kp} Y_{jk} = \sum_{n \in N_j} D_{jp} U_j^n, \forall p \in P, \forall j \in J \tag{11}$$

$$\sum_{j \in J} Y_{jk} = 1, \forall k \in K \tag{12}$$

$$\sum_{j \in J} G_{ijp} \geq 1, \forall p \in P, \forall i \in I \tag{13}$$

$$\sum_{n \in N_j} D_{jp} U_j^n = \sum_{i \in I} V_{ijp} G_{ijp}, \forall p \in P, \forall j \in J \tag{14}$$

$$\sum_{j \in J} V_{ijp} = D_{ip}, \forall p \in P, \forall i \in I \tag{15}$$

$$\sum_{j \in J} V_{ijp} \leq b_{ip}, \forall i \in I \tag{16}$$

$$SS_{kp} = z_\alpha \sqrt{lt_{kp} \sigma_{kp}^2}, \forall p \in P, \forall k \in K \tag{17}$$

$$MK_{kp} = \sqrt{lt_{kp}\sigma_{kp}^2[f(z_\alpha) - z_\alpha\psi(z_\alpha)]}, \forall p \in P, \forall k \in K \quad (18)$$

$$RK_{kp} = lt_{kp}\mu_{kp} + SS_{kp}, \forall p \in P, \forall k \in K \quad (19)$$

$$RK_{jp} = (\sum_k (lt_{jp} + lt_{kp})\mu_{kp} + SS_{kp})Y_{jk}, \forall p \in P, \forall j \in J \quad (20)$$

$$RK_{ip} = (\sum_k lt_{ip}\mu_{kp} + (\sum_j \sum_k (lt_{jp} + lt_{kp})\mu_{kp} + SS_{kp})Y_{jk})G_{ijp}, \forall p \in P, \forall i \in I \quad (21)$$

$$T = \frac{Q_{ip}}{D_{ip}} = \frac{NP_{jp}Q_{jp}}{D_{jp}} = \frac{NP_{jp}NP_{kp}Q_{kp}}{\mu_{kp}}, \forall p \in P, \forall k \in K, \forall j \in J \quad (22)$$

$$NP_{kp} = E, \forall p \in P, \forall k \in K \quad (23)$$

$$NP_{jp} = Z, \forall p \in P, \forall j \in J \quad (24)$$

$$\sum_{p \in P} Q_{kp} = Q_k, \forall k \in K \quad (25)$$

$$\sum_{p \in P} Q_{jp} = Q_j, \forall j \in J \quad (26)$$

$$\sum_{p \in P} Q_{ip} = Q_i, \forall i \in I \quad (27)$$

$$X_j = \left\lfloor \frac{Q_j}{pp} \right\rfloor, \forall j \in J \quad (28)$$

$$X_i = \left\lfloor \frac{Q_i}{pp} \right\rfloor, \forall i \in I \quad (29)$$

$$U_j^n \in \{0,1\}, \forall j \in J, \forall n \in N_j \quad (30)$$

$$Y_{jk} \in \{0,1\}, \forall j \in J, \forall k \in J \quad (31)$$

$$R_{klv}^o \in \{0,1\}, \forall k, l \in M, \forall o \in O_{kl}, \forall v \in V \quad (32)$$

$$G_{ijp} \in \{0,1\}, \forall p \in P, \forall j \in J, \forall i \in I \quad (33)$$

$$M_{kv} \geq 0, \forall k \in K, \forall v \in V \quad (34)$$

$$Q_{ip}, Q_{jp}, Q_{kp} \geq 0, \forall p \in P, \forall i \in I, \forall j \in J, \forall k \in K \quad (35)$$

$$T \geq 0 \quad (36)$$

$$E, Z, NP_{jp}, NP_{kp} \geq 1, E, Z, NP_{jp}, NP_{kp} \in int, \forall j \in J, \forall k \in K, \forall p \in P \quad (37)$$

$$V_{ijp} \geq 0, \forall p \in P, \forall j \in J, \forall i \in I \quad (38)$$

Equation (1) is the total cost. Constraints (2) guarantee that each traditional market is served exactly once by a vehicle. Constraints (3) ensure that products sent in one vehicle route may not exceed the vehicle's capacity. Constraints (4) are the subtour elimination. Constraints (5) are the flow conservation. Constraints (6) guarantee that

only one UCC per route. Constraints (7) connect allocation and routing decisions. Constraints (8) guarantee that each vehicle can only traverse one link. Constraints (9) guarantee that each UCC can only have one level capacity. Constraints (10) guarantee that a UCC must not supply traditional markets beyond its capacity. Constraints (11) guarantee that demands in a UCC for each product is the sum of the demands for the traditional markets served for each product. Constraints (12) guarantee that each traditional market is supplied exactly once by a UCC. Constraints (13) guarantee each province of supplier can service more than one UCC and one product. Constraints (14) guarantee that demands at province of supplier are the demands for each product that can be supplied to UCC without exceeding its capacity. Constraints (15) guarantee that demands of each UCC for each product must be fulfilled by province of supplier. Constraints (16) guarantee that demands at province of suppliers are the demands for each product supplied to UCC served. Constraints (22) are single cycle time. Constraints (23) are frequency of order for traditional markets. Constraints (24) are frequency of order for UCCs. Constraints (25) are lot size of all products in traditional market. Constraints (26) are lot size of all products in UCC. Constraints (27) are lot size of all products in province of supplier. Constraints (30)-(38) are the constraints for decision variables.

The LIRP model developed in this paper is MINLP (mixed integer nonlinear programming) model. Since LIRP belongs to the class of NP-hard problems, the application of the MINLP model is limited to small data (Ahmadi-Javid & Azad, 2010). To apply the model in a real system case which is Jakarta, it needs method of heuristic. The method of heuristic based on algorithm of SA (simulated annealing) is developed in this paper. SA is algorithm of local search (meta-heuristic) that is capable of escaping from local optima. It is used to solve discrete and to a lesser extent, continuous optimization problems (Henderson, Jacobson & Johnson, 2003). The LIRP consists of location and routing problems which are discrete optimization problems and inventory problem which is continuous optimization problems. SA is appropriate to solve the model in this paper.

4. Solution Method

As it was mentioned previously, to solve the LIRP model, this paper develops method of heuristic based on algorithm of SA. Solution resulted from the method of heuristic is compared to the solution resulted from method of optimal (the MINLP). The method of heuristic uses parameters as follows.

Parameters of the method of heuristic	
I_0	initial temperature
I_a	final temperature
I_c	current temperature
β_0	initial solution
β_a	final solution
β_c	current solution
θ	cooling rate
C_{max}	iteration maximum number at every level of temperature
Δ	$TC(\beta_c) - TC(\beta_a)$
r	random number between 0 and 1
$TC(\beta_0)$	value of objective function for initial solution
$TC(\beta_a)$	value of objective function for final solution
$TC(\beta_c)$	value of objective function for current solution

Pseudo code of the method of heuristic is given in Figure 3.

```

Take  $\beta_0$ 
Set the SA parameters  $\theta, C_{max}, I_a, I_0$ 
Initial  $\beta_a = \beta_0, I_c = I_0, i = 1$ 
While  $I_c > I_a$ 
    For  $i = 1: C_{max}$ 
         $r \leftarrow U(0,1)$ 
        If  $r < 1/3$ 
            MoveA
        Else If  $r < 2/3$ 
            MoveB
        Else
            MoveC
        End If
         $r \leftarrow U(0,1)$ 
        If  $r < 1/2$ 
            MoveD
        Else
            MoveE
        End If
        MoveF
        Generate  $\beta_c$ 
         $i = i + 1$ 
        If  $\beta_c$  satisfies all the constraints
             $\Delta TC(\beta_c) - TC(\beta_a)$ 
            If  $\Delta < 0$ 
                 $\beta_a = \beta_c$ 
            Else
                 $r \leftarrow U(0,1)$ 
                If  $r < e^{\frac{\Delta}{I_c}}$ 
                     $\beta_a = \beta_c$ 
                End If
            End If
        End If
    End For
     $I_c = \theta I_c$ 
End While
    
```

Figure 3. Pseudo code of the method of heuristic

All moves used in this paper are adopted from Saragih et al. (2019).

5. Computational Experiments

Example of solution for the LIRP model is given in Figure 4. The solution is resulted from method of optimal by running the model in LINGO 12.0. Data used for the problem in Figure 4 are described as follows.

Traditional market/product	μ_{kp} (kg/day)		σ^2_{kp} (kg/day)		a_{kp} (Rp/order)		h_{kp} (Rp/kg/period)		b_{kp} (Rp/kg)		I_{kp} (day)	
	1	2	1	2	1	2	1	2	1	2	1	2
3	10	15	2	2	4	4	2	2	1	1	0.25	0.25
4	20	25	3	3	4	4	2	2	1	1	0.25	0.25
5	30	35	4	4	4	4	2	2	1	1	0.25	0.25
6	40	45	5	5	4	4	2	2	1	1	0.25	0.25

Table 2. Data used in traditional market k

UCC/product	b_j^n (kg/day)		f_j^n (Rp/day)		a_{jp} (Rp/order)		h_{jp} (Rp/kg/period)		It_{jp} (day)		Vehicle capacity (kg)
	1	2	1	2	1	2	1	2	1	2	
1	300	300	200	200	5	5	3	3	0.25	0.25	30
2	200	200	100	100	5	5	3	3	0.25	0.25	

Table 3. Data used in UCC j

Province of supplier/product	Capacity (Kg/day)		a_{ip} (Rp/order)		h_{ip} (Rp/kg/period)		It_{ip} (day)		Truck capacity (kg)
	1	2	1	2	1	2	1	2	
1	0	60	12	6	8	4	0.5	0.25	60
2	100	60	6	6	4	4	0.25	0.25	

Table 4. Data used in province of supplier i

Node	Distance link 1 (km)						Distance link 2 (km)					
	1	2	3	4	5	6	1	2	3	4	5	6
1	0	3	2	1	5	4	0	2	3	2	4	3
2	3	0	4	2	3	1	2	0	5	1	4	2
3	2	4	0	5	2	1	3	5	0	4	1	2
4	1	2	5	0	2	1	2	1	4	0	3	2
5	5	3	2	2	0	4	4	4	1	3	0	5
6	4	1	1	1	4	0	3	2	2	2	5	0

Table 5. Distance between nodes

Node	Time loss link 1 (hour)						Time loss link 2 (hour)					
	1	2	3	4	5	6	1	2	3	4	5	6
1	0	3	4	5	1	2	0	4	3	4	2	3
2	3	0	2	4	3	5	4	0	1	5	2	4
3	4	2	0	1	4	5	3	1	0	2	5	4
4	5	4	1	0	4	5	4	5	2	0	3	4
5	1	3	4	4	0	2	2	2	5	3	0	1
6	2	5	5	5	2	0	3	4	4	4	1	0

Table 6. Time loss between nodes

Opened UCC is UCC 1 with capacity level 2. UCC 1 is supplied by province of supplier 1 and 2. Province of supplier 1 only supplies product 1 because the product that is available at province of supplier 1 is only product 1. Province of supplier 2 can supply product 1 and product 2 because on province of supplier 2 has both of the products. Opened UCC 1 serves all traditional markets by forming vehicle routes. There are 2 tours of vehicle routes established to serve the traditional markets. Tour 1 consists of UCC 1 - TM 3 - TM 4 - UCC 1. From UCC 1 to TM 3, the vehicle traverses link 1, from TM 3 to TM 4, the vehicle traverses link 1, and from TM 4 to UCC 1 traversed link is link 2. Tour 2 consists of UCC 1 - TM 5 - TM 6 - UCC 1. From UCC 1 to TM 5, the traversed link is link 1, from TM 5 to TM 6, the traversed link is link 2, and from TM 6 to UCC 1, the traversed link is link 1.

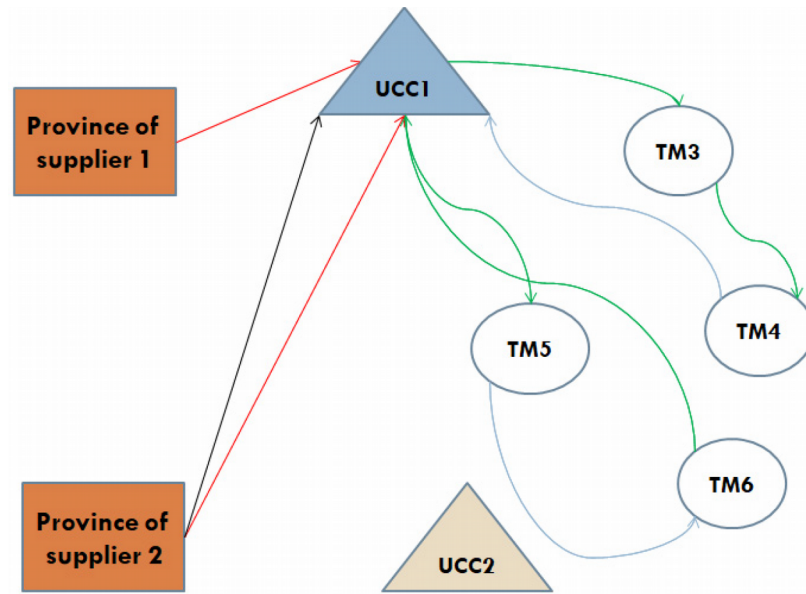


Figure 4. Solution of the illustration of system studied

Comparison for method of heuristic and method of optimal can be seen in Table 7. The efficiency for method of heuristic is 3.1% on average.

No.	# province of supplier	# UCC	# traditional markets	Method of optimal		Method of heuristic		Gap (%)	
				Total cost (Rp/day)	CPU times (s)	Total cost (Rp/day)	CPU times (s)	Total cost	
1	2	2	4	1938	172800 limit	2003	23	3.3	
2	3	2	4	2183	172800 limit	2215	28	1.5	
3	2	3	4	NA	172800 limit	1961	30		
4	3	3	4	2162	172800 limit	2258	21	4.5	
5	2	2	5	2414	172800 limit	2413	23	0.0	
6	3	2	5	2591	23302	2759	25	6.5	
7	2	3	5	NA	172800 limit	2447	31		
8	3	3	5	NA	172800 limit	2783	27		
Average									3.1

Table 7. Comparison for both solution method

6. Application in City of Jakarta

Method of heuristic for the LIRP model is applied in city of Jakarta. There are two links considered. Link 1 is road with the longest distance and link 2 is road with the shortest distance. Illustration of link 1 and link 2 can be seen in Figure 5. Figure 5 is location map of Cempaka Putih Market and Gembrong Inpres Market which are connected by 2 links. Link 1 is taken through Jl. Letjen Suprpto and Jl. Pangkalan Asem Raya. Link 2 is taken through Jl. Cempaka Putih Barat III and Jl. Cempaka Raya.

There are 12 province of suppliers, 4 potential UCCs, 165 traditional markets, and 10 products in the food supply chain system of Jakarta. For traditional markets, some of the results are given in Table 8.

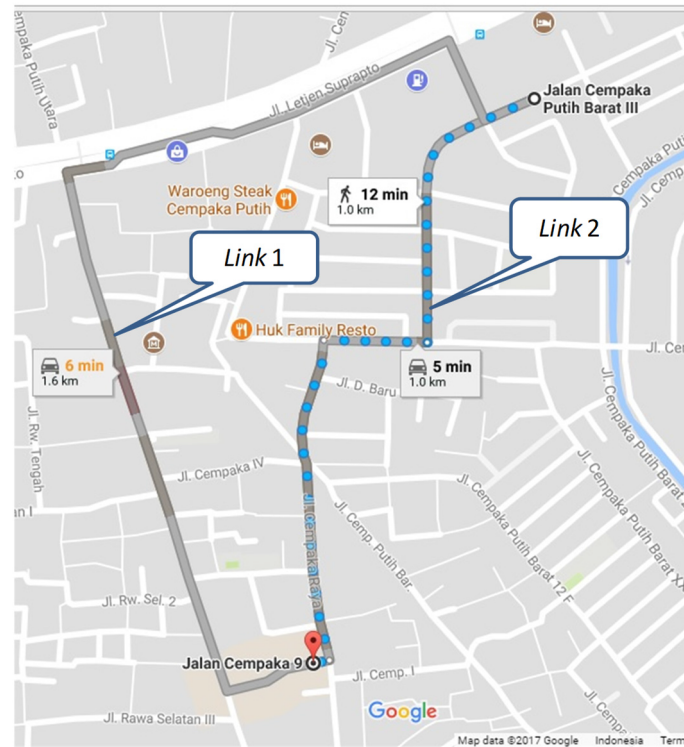


Figure 5. Location map and connecting links

Retail market	Demands (kg/day)		Lot size (kg)		Safety stock (kg)		Order frequency	
	Product 2	Product 7	Product 2	Product 7	Product 2	Product 7	Product 2	Product 7
1	96	542	38.4	217.0	6.33	43.11	1	1
2	96	542	38.4	217.0	6.79	42.36	1	1
3	79	447	31.6	178.9	6.23	36.16	1	1
4	79	447	31.6	178.9	5.84	33.33	1	1
5	26	147	10.4	58.7	2.05	9.93	1	1
6	26	147	10.4	58.7	1.86	11.87	1	1
7	26	147	10.4	58.7	1.78	10.28	1	1
8	26	147	10.4	58.7	1.99	10.94	1	1
9	58	325	23.0	130.2	4.07	25.64	1	1
10	58	325	23.0	130.2	4.07	24.25	1	1
11	40	225	15.9	90.1	3.05	15.23	1	1
12	40	225	15.9	90.1	2.63	16.95	1	1
13	40	225	15.9	90.1	2.85	15.41	1	1
14	40	225	15.9	90.1	3.14	18.05	1	1
15	9	53	3.7	21.2	0.73	4.09	1	1
16	9	53	3.7	21.2	0.63	4.17	1	1
17	9	53	3.7	21.2	0.72	3.98	1	1
18	9	53	3.7	21.2	0.65	4.24	1	1
19	9	53	3.7	21.2	0.62	3.70	1	1
20	9	53	3.7	21.2	0.67	3.78	1	1

Retail market	Demands (kg/day)		Lot size (kg)		Safety stock (kg)		Order frequency	
	Product 2	Product 7	Product 2	Product 7	Product 2	Product 7	Product 2	Product 7
21	9	53	3.7	21.2	0.62	3.86	1	1
22	9	53	3.7	21.2	0.66	3.58	1	1
23	156	881	62.3	352.4	12.49	71.21	1	1
24	27	155	11.0	62.2	2.07	11.47	1	1
25	27	155	11.0	62.2	1.90	11.12	1	1
26	27	155	11.0	62.2	1.88	11.70	1	1
27	27	155	11.0	62.2	2.05	10.39	1	1
28	36	204	14.4	81.5	2.84	14.43	1	1
29	36	204	14.4	81.5	2.63	14.27	1	1
30	96	542	43.5	245.7	7.94	46.67	1	1
31	96	542	28.1	159.1	5.24	28.15	1	1
32	79	447	28.1	159.1	4.76	27.84	1	1
33	79	447	28.1	159.1	5.54	30.78	1	1
...
154	41	229	9.1	51.6	1.72	9.70	1	1
155	41	229	9.1	51.6	1.78	9.61	1	1
156	41	229	9.1	51.6	1.67	9.98	1	1
157	41	229	9.1	51.6	1.67	10.34	1	1
158	23	129	9.1	51.6	1.60	9.80	1	1
159	23	129	9.1	51.6	1.75	10.16	1	1
160	23	129	9.1	51.6	1.67	9.51	1	1
161	23	129	10.9	61.8	2.12	10.58	1	1
162	23	129	10.9	61.8	1.89	10.46	1	1
163	23	129	10.9	61.8	1.98	12.29	1	1
164	23	129	42.1	238.1	7.45	46.90	1	1
165	27	155	42.1	238.1	8.51	45.65	1	1
Total	5301	29976	2120	11991	392	2227		

Table 8. Traditional markets' results

For UCCs, some of the results are given in Table 9 and Table 10.

UCC	Demands (kg/day)		Lot size (kg)		Order frequency	
	Product 2	Product 7	Product 2	Product 7	Product 2	Product 7
1	1075	6078	430	2431	1	1
2	1265	7156	506	2862	1	1
3	1505	8511	602	3405	1	1
4	1456	8231	582	3293	1	1
Total	5301	29976	2120	11991		

Table 9. UCCs' results (1)

UCC	Vehicle capacity (Kg)	Vehicles (Unit)	Route of the vehicles													
1	8000	1	1	14	16	17	13	9	8	1						
		2	1	7	41	36	39	1								
		3	1	34	6	5	1									
		4	1	27	1											
2	8000	5	2	138	137	142	135	140	141	136	129	130	134	2		
		6	2	108	109	133	112	114	110	118	2					
		7	2	111	113	115	15	22	23	26	31	30	28	40	2	
		8	2	139	119	120	121	149	117	116	2					
3	8000	9	3	65	60	61	58	63	53	57	59	42	45	49	44	47
		10	3	73	71	69	66	70	51	54	55	52	56	50	62	3
		11	3	165	167	166	161	168	169	3						
		12	3	64	96	92	94	93	90	91	88	83	82	29	25	21
		13	3	35	38	37	3									
4	8000	14	4	154	155	153	156	157	159	163	160	162	164	158	4	
		15	4	150	95	102	103	104	125	126	124	122	148	123	127	
		16	4	100	101	98	99	86	97	89	87	75	74	68	72	67
		17	4	85	84	107	106	105	77	80	76	79	78	81	33	32
		18	4	145	144	147	132	143	4							

Table 10. UCCs' results (2)

Traversed links for every vehicle route is given in Table 11.

No.	Route of the vehicles										Traversed links								
1	1	14	16	17	13	9	8	1				1	2	2	1	2	2	1	
2	1	7	41	36	39	1					1	1	1	2	1				
3	1	34	6	5	1						1	2	2	1					
4	1	27	1							1	1								
5	2	138	137	142	135	140	141	136	129	130	1	1	1	1	1	1	2	2	1
6	2	108	109	133	112	114	110	118	2	1	1	2	2	1	1	2	1		
7	2	111	113	115	15	22	23	26	31	30	1	2	1	1	2	1	1	2	1
8	2	139	119	120	121	149	117	116	2	1	2	1	2	2	2	2	1		
9	3	65	60	61	58	63	53	57	59	42	1	1	1	2	1	2	1	1	1
		45	49	44	47	3					1	1	1	2	1				

No.	Route of the vehicles										Traversed links								
10	3	73	71	69	66	70	51	54	55	52	1	2	1	1	1	1	2	2	1
		56	50	62	3							1	1	2	1				
11	3	165	167	166	161	168	169	3			1	1	1	2	2	1	1		
12	3	64	96	92	94	93	90	91	88	83	1	2	1	1	1	1	1	1	1
		82	29	25	21	20	19	24	18	10		1	2	2	2	2	1	1	1
		11	12	3								2	1	1	1				
13	3	35	38	37	3						1	2	1	1					
14	4	154	155	153	156	157	159	163	160	162	1	1	2	1	1	2	2	1	2
		164	158	4								1	1	1					
15	4	150	95	102	103	104	125	126	124	122	1	2	1	1	1	2	2	2	1
		148	123	127	151	152	146	4				1	1	1	1	1	2	1	
16	4	100	101	98	99	86	97	89	87	75	1	2	2	1	2	2	2	2	1
		74	68	72	67	43	48	46	4			1	2	1	1	1	2	1	1

Table 11. Traversed links for the vehicle routes

For province of suppliers, the results are given in Table 12.

Supplier	T (day)	Demands (kg/day)		Lot size (kg)	
		Product 2	Product 7	Product 2	Product 7
1	0.4	5301	0	2120	0
2		0	0	0	0
3		0	0	0	0
4		0	0	0	0
5		0	0	0	0
7		0	0	0	0
8		0	29976	0	11991
9		0	0	0	0
10		0	0	0	0
11		0	0	0	0
12		0	0	0	0

Table 12. Province of suppliers' results

6.1. Performance Analysis

In Table 13, it can be seen that the new design of the food supply chain provides a more efficient total cost by 18%. This is due to benefit provided by the UCCs in terms of availability which can be maintained at 95% level. The availability of the existing system only 76%. As it was mentioned previously, UCCs are logistics facilities where consolidation and coordination activities are performed. In the existing supply chain system, there is no both activities. Without consolidation activity, inventory policies are carried out independently in each traditional market and in each province of supplier. In addition, without coordination activity, there is no vehicle routes formed since vehicles used to deliver goods are the vehicles originating directly from each province of supplier.

The new design also reduces the number of vehicles by 73% due to the use of vehicles together at UCCs. Moreover, with the new design of supply chain in Jakarta, there is opportunity to use environmentally friendly and

fuel-efficient goods vehicles (green vehicles) that can be used at UCCs to deliver goods to traditional markets in urban areas.

No.	Performances	New design of supply chain system	Existing supply chain system
1	Total cost	Rp1,878,425,223/day	Rp2,209,950,923/day
2	Availability/service level	95%	76%
3	Number of vehicles	39 vehicles/day	165 vehicles/day

Table 13. Comparison of the performances

7. Conclusion

This paper has successfully developed a model of LIRP that considers multiple links to represent the road networks in cities. There is no model of LIRP that considers multiple links; therefore, this paper gives contribution in the LIRP models that were developed before. The model developed in this paper represents more realistic real systems where there are multiple road networks that connect places in urban areas.

To apply the model in a real system, which is Jakarta, this paper develops method of heuristic based on algorithm of simulated annealing. The new design resulted from the application of the model improves both the effectiveness and efficiency of Jakarta's food supply chain. Total cost reduces by 18%, availability/service level increases from 76% to 95%, and number of vehicles reduces by 73%.

Number of links considered in the real system is 2 links which represent the longest (link 1) and the shortest distance (link 2). It can be seen from the results (Table 11) that the traversed links are not always the shortest ones. This is due to cost of congestion which also considered when deciding the vehicle routes. In cities, distance is not the only consideration to decide the traversed links. This paper shows that the distance can be short, but if the traffic is congested then the link is not traversed.

Since the average gap in terms of total cost between method of heuristic and method of optimal is 3.1%, this paper also provides opportunities for future work to develop more efficient method of heuristic to solve the model in large data.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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Journal of Industrial Engineering and Management, 2021 (www.jiem.org)



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