Single-tier City Logistics Model for Multi Products

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***Abstract*— Single-tier city logistics system consists of three entities which are suppliers, UCCs (urban consolidation centers), and retailers. This paper develops a model for single-tier city logistics system with multi products that has never been developed before. This paper also considers traffic congestion in the model so it more represents the real system in a city. Demands of the products follow a normal distribution. The problems that will be answered in this paper are how to determine the location of suppliers, to allocate retailers to opened UCCs, to assign suppliers to opened UCCs, to control inventory in the three entities involved, and to determine the route of the vehicles from opened UCCs to retailers. All the decisions will be simultaneously optimized. The model is solved using LINGO 12. Three numerical examples with different values of parameters are conducted to test the proposed model. All numerical examples show that the proposed model results logical solution.**

***Keywords*—** city logistics, inventory control, location decision, multi echelon, vehicle routing

1. Introduction

This paper develops mathematical model for single-tier city logistics system with multi product. According to [1], city logistics is “the process for totally optimising the logistics and transport activities by private companies with the support of advanced information systems in urban areas considering the traffic environment, its congestion, safety and energy savings within the framework of a market economy”. Based on that definition, this paper will develop single-tier city logistics model that also considers traffic congestion.

Single-tier city logistics system consists of three entities which are point of supplies, logistics facilities, and point of demands. The entities involved are point of supplies that are called suppliers, logistics facilities that are called UCC (urban consolidation centers), and point of demands that are called retailers. The problems that will be adressed in this paper are how to determine the location of UCCs, to allocate retailers to opened UCCs, to assign suppliers to opened UCCs, to control inventory in the three entities involved, and to determine the route of the vehicles from opened UCCs to retailers. The problems that have been described will be simultaneously optimized. Demands of the products follow a normal distribution.

There are only few papers that developed mathematical model in the area of city logistics. Some of them is [2] that developed a model to determine the optimal size and location planning of public logistics terminals. Ref. [2] considered traffic conditions in their model and used Genetic Algorithm to solve the model. The number of product considered was single. Ref. [2] did not consider inventory and vehicle route in their model. Another paper is [3] that developed a model to determine the location of satellites and quantity of product that being sent. Ref. [3] used CPLEX to solve the model. The number of product considered was single. Ref. [3] also did not consider inventory and vehicle route in their model.

Another paper that developed mathematical model in the area of city logistics is [4]. Ref. [4] developed a model with similar problems to this paper but [4] only considered single product and did not consider traffic congestion. From papers that have been described previously, it can be known that there is no paper that has developed city logistics model with the addressed problems in this paper with considering multi product and traffic congestion.

2. Methodolody

As it was mentioned before, the adressed problems in this paper are similar to [4]. Therefore, this paper will use [4] as the reference model to develop the proposed model. The illustration of single-tier city logistics system can be seen in Figure 1. Suppliers and UCCs are located outside of the city and retailers are located inside of the city.

The traffic congestion that will be considered in this paper is presented as the marginal external congestion cost parameter that emerges in the routing cost. According to [5], the marginal external congestion cost occurs when an additional vehicle on the road transport network reduces the speed of the other transport users in the network. The marginal external congestion cost is resulted from multiplication of the time loss suffered by other road users if an additional PCU (passenger car units) joins the traffic flow with value of time. To calculate the

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marginal external congestion cost in this paper, it is assumed that traffic conditions is homogeneous and road networks are represented as one-link system.

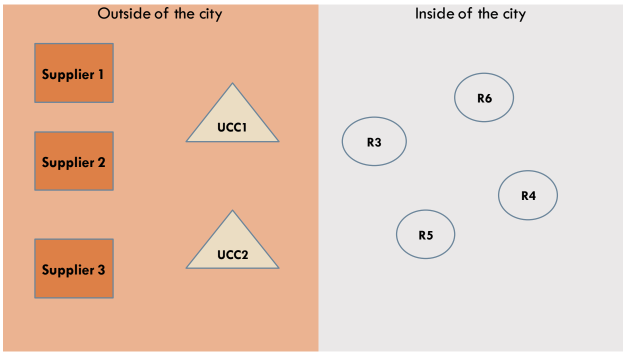

Figure 1. Single-tier city logistics system.

For the marginal external congestion cost is calculated in the routing cost in addition to traditional transportation cost that based on distance, then there is a trade–off when determine vehicle route.

3. Mathematical Model

Mathematical model for single-tier city logistics model for multi product is described as follows.

3.1 Index sets

K set of retailers
J set of potential UCCs
N_j set of capacity levels available to UCC $(j \in J)$
I set of suppliers
P set of products
V set of vehicles
M merged set of retailers and potential UCCs, i.e. $(K \cup J)$

3.2 Indices

k index of retailers
j index of UCCs
n index of capacity levels available to UCC
i index of suppliers
p index of products
v index of vehicles

3.3 Parameters and notations

At retailer

μ_{kp} mean of demand at retailer k for product p (Unit/day) $(\forall k \in K, \forall p \in P)$
σ^2_{kp} variance of demand at retailer k for product p (Unit^2/day^2) $(\forall k \in K, \forall p \in P)$
h_{kp} inventory holding cost at retailer k for product p (Rp/unit/day) $(\forall k \in K, \forall p \in P)$
a_{kp} ordering cost at retailer k for product p (Rp/order) $(\forall k \in K, \forall p \in P)$
lt_{kp} lead time of retailer k for product p (Day) $(\forall k \in K, \forall p \in P)$
s_{kp} shortage cost at retailer k for product p (Rp/unit) $(\forall k \in K, \forall p \in P)$
α fill rate
z_α z value on the standard normal distribution for α level
$f(z_\alpha)$ ordinate of z_α
$\psi(z_\alpha)$ partial expectations of z_α

At UCC

f^n_j fixed cost for opening and operating UCC j with capacity level n (Rp/day) $(\forall j \in J, \forall n \in N_j)$
b^n_j capacity with level n for UCC j (Unit/day) $(\forall j \in J, \forall n \in N_j)$
d_{kl} distance between node k and node l (Km) $(\forall k, l \in M)$
t_{kl} time loss between node k and node l (Hour) $(\forall k, l \in M)$
ca transportation cost (Rp/km)
cb value of time (Rp/hour)
h_{jp} inventory holding cost at UCC j for product p (Rp/unit/day) $(\forall j \in J, \forall p \in P)$
a_{jp} ordering cost at UCC j for product p (Rp/order) $(\forall j \in J, \forall p \in P)$
lt_{jp} lead time of UCC j for product p (Day) $(\forall j \in J, \forall p \in P)$
vc capacity of vehicle (Unit)

At supplier

h_{ip} inventory holding cost at supplier i for product p (Rp/unit/day) $(\forall i \in I, \forall p \in P)$
a_{ip} ordering cost at supplier i for product p (Rp/order) $(\forall i \in I, \forall p \in P)$
lt_{ip} lead time of supplier i for product p (Day) $(\forall i \in I, \forall p \in P)$
b_{ip} capacity for supplier i for product p (Unit/day) $(\forall i \in I, \forall p \in P)$

At system

w transportation cost of truck (Rp/truck)
pp capacity of truck (Unit)
B number of retailers contained in set K, i.e. $B = |K|$

3.4 Decision variables

At retailer

NP_{kp} order frequency of retailer k for product p $(\forall k \in K, \forall p \in P)$

E order frequency of every retailer and product

Q_{kp} lot size of retailer k for product p (Unit) $(\forall k \in K, \forall p \in P)$

Q_k total lot size of retailer k (Unit) $(\forall k \in K)$

MK_{kp} number of shortage at retailer k for product p (Unit) $(\forall k \in K, \forall p \in P)$

RK_{kp} reorder point at retailer k for product p (Unit) $(\forall k \in K, \forall p \in P)$

SS_{kp} safety stock at retailer k for product p (Unit) $(\forall k \in K, \forall p \in P)$

At UCC

U_j^n 1 if distribution center j is opened with capacity level n, 0 if otherwise $(\forall j \in J, \forall n \in N_j)$

D_{jp} demand of UCC j for product p (Unit/day) $(\forall j \in J, \forall p \in P)$

Y_{jk} 1 if retailer k is assigned to UCC j, 0 if otherwise $(\forall j \in J, \forall k \in K)$

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 (Unit) $(\forall j \in J, \forall p \in P)$

Q_j total lot size of UCC j (Unit) $(\forall j \in J)$

RK_{jp} reorder point at UCC j for product p (Unit) $(\forall j \in J, \forall p \in P)$

R_{klv} 1 if k precedes l in route of vehicle v, 0 if otherwise $(\forall k, l \in M, \forall v \in V)$

M_{kv} auxiliary variable defined for retailer k for subtour elimination in route of vehicle v $(\forall k \in K, \forall v \in V)$

X_j number of truck at UCC j (Truck) $(\forall j \in J)$

At supplier

D_{ip} demand of supplier i for product p (Unit/day) $(\forall i \in I, \forall p \in P)$

Q_{ip} lot size of supplier i for product p (Unit) $(\forall i \in I, \forall p \in P)$

Q_i total lot size of supplier i (Unit) $(\forall i \in I)$

RK_{ip} reorder point at supplier i for product p (Unit) $(\forall i \in I, \forall p \in P)$

X_i number of truck at supplier i (Truck) $(\forall i \in I)$

G_{ijp} 1 if supplier i supplies UCC j for product p, 0 if otherwise $(\forall i \in I, \forall j \in J, \forall p \in P)$

V_{ijp} amount of demand of UCC j for product p supplied by supplier i $(\forall i \in I, \forall j \in J, \forall p \in P)$

At system

TC total cost (Rp/day)

T single cycle time (Day)

3.5 The model

The objective function includes the following costs:

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 retailers, given as $\frac{E}{T} \sum_{v \in V} \sum_{k \in M} \sum_{l \in M} (d_{kl} ca + t_{kl} cb) R_{klv}$.
3. The expected inventory cost in retailers, 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
$$\sum_{j \in J} \sum_{p \in P} \left[\begin{array}{l} \frac{a_{jp} D_{jp}}{Q_{jp}} + h_{jp} \left(\frac{Q_{jp}}{2} + \sum_k \left(lt_{kp} \mu_{kp} + SS_{kp} \right) Y_{jk} \right) \\ + wX_j \frac{Z}{T} \end{array} \right]$$
5. The expected inventory cost in suppliers, given as
$$\sum_{i \in I} \sum_{p \in P} \left[\begin{array}{l} \frac{a_{ip} D_{ip}}{Q_{ip}} + h_{ip} \left(\begin{array}{l} \frac{Q_{ip}}{2} + \\ \left(\sum_j \sum_k \left(\begin{array}{l} \left(lt_{jp} + lt_{kp} \right) \mu_{kp} \\ + SS_{kp} \end{array} \right) Y_{jk} \right) G_{ijp} \end{array} \right) + \\ wX_i \frac{1}{T} \end{array} \right]$$

Mathematical model of single-tier city logistics model for multi products is given below.

Objective function:

$$\min TC =$$

$$\sum_{j\in J}\sum_{n\in N_j} f_j^n U_j^n + \frac{E}{T}\sum_{v\in V}\sum_{k\in M}\sum_{l\in M}(d_{kl}ca + t_{kl}cb)R_{klv} + \sum_{k\in K}\sum_{p\in P}\left[\frac{a_{kp}\mu_{kp}}{Q_{kp}} + h_{kp}\left(\frac{Q_{kp}}{2} + SS_{kp}\right) + s_{kp}MK_{kp}\left(\frac{\mu_{kp}}{Q_{kp}}\right)\right] +$$
$$\sum_{j\in J}\sum_{p\in P}\left[\frac{a_{jp}D_{jp}}{Q_{jp}} + h_{jp}\left(\frac{Q_{jp}}{2} + \sum_{k}\left(lt_{kp}\mu_{kp} + SS_{kp}\right)Y_{jk}\right) + wX_j\frac{Z}{T}\right] + \quad (1)$$
$$\sum_{i\in I}\sum_{p\in P}\left[\frac{a_{ip}D_{ip}}{Q_{ip}} + h_{ip}\left(\frac{Q_{ip}}{2} + \left(\sum_{j}\sum_{k}\begin{pmatrix}\left(lt_{jp} + lt_{kp}\right)\mu_{kp} \\ + SS_{kp}\end{pmatrix}Y_{jk}\right)G_{ijp}\right) + wX_i\frac{1}{T}\right]$$

Subject to:

$$\sum_{v\in V}\sum_{l\in M} R_{klv} = 1, \forall k\in K \quad (2)$$

$$\sum_{l\in K}\sum_{k\in M} Q_l R_{klv} \le vc, \forall v\in V \quad (3)$$

$$M_{kv} - M_{lv} + \left(B\times R_{klv}\right) \le B-1, \quad \forall k,l\in K, \forall v\in V \quad (4)$$

$$\sum_{l\in M} R_{klv} - \sum_{l\in M} R_{lkv} = 0, \forall k\in M, \forall v\in V \quad (5)$$

$$\sum_{j\in J}\sum_{k\in K} R_{jkv} \le 1, \forall v\in V \quad (6)$$

$$\sum_{l\in M} R_{klv} + \sum_{l\in M} R_{jlv} - Y_{jk} \le 1, \quad \forall j\in J, \forall k\in K, \forall v\in V \quad (7)$$

$$\sum_{n\in N_j} U_j^n \le 1, \forall j\in J \quad (8)$$

$$\sum_{k\in K}\sum_{p\in P}\mu_{kp}Y_{jk} \le \sum_{n\in N_j} b_j^n U_j^n, \forall j\in J \quad (9)$$

$$\sum_{k\in K}\mu_{kp}Y_{jk} = \sum_{n\in N_j} D_{jp}U_j^n, \forall p\in P, \forall j\in J \quad (10)$$

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

$$\sum_{j\in J} G_{ijp} \ge 1, \forall i\in I \quad (12)$$

$$\sum_{n\in N_j} D_{jp}U_j^n = \sum_{i\in I} V_{ijp}G_{ijp}, \forall p\in P, \forall j\in J \quad (13)$$

$$\sum_{j\in J} V_{ijp} = D_{ip}, \forall p\in P, \forall i\in I \quad (14)$$

$$\sum_{j\in J} V_{ijp} \le b_{ip}, \forall i\in I \quad (15)$$

$$SS_{kp} = z_\alpha\sqrt{lt_{kp}\sigma_{kp}^2}, \forall p\in P, \forall k\in K \quad (16)$$

$$MK_{kp} = \sqrt{lt_{kp}\sigma_{kp}^2}\left[f\left(z_\alpha\right) - z_\alpha\psi\left(z_\alpha\right)\right], \quad \forall p\in P, \forall k\in K \quad (17)$$

$$RK_{kp} = lt_{kp}\mu_{kp} + SS_{kp}, \forall p\in P, \forall k\in K \quad (18)$$

$$RK_{jp} = \left(\sum_{k}\left(lt_{jp} + lt_{kp}\right)\mu_{kp} + SS_{kp}\right)Y_{jk}, \quad \forall p\in P, \forall j\in J \quad (19)$$

$$RK_{ip} = \begin{pmatrix}\sum_{k} lt_{ip}\mu_{kp} + \\ \left(\sum_{j}\sum_{k}\left(lt_{jp} + lt_{kp}\right)\mu_{kp} + SS_{kp}\right)Y_{jk}\end{pmatrix}G_{ijp}, \quad \forall p\in P, \forall i\in I \quad (20)$$

$$T = \frac{Q_{ip}}{D_{ip}} = \frac{NP_{jp}Q_{jp}}{D_{jp}} = \frac{NP_{jp}NP_{kp}Q_{kp}}{\mu_{kp}} \quad (21)$$

$$NP_{kp} = E, \forall p\in P, \forall k\in K \quad (22)$$

$$NP_{jp} = Z, \forall p\in P, \forall j\in J \quad (23)$$

$$\sum_{p\in P} Q_{kp} = Q_k, \forall k\in K \quad (24)$$

$$\sum_{p\in P} Q_{jp} = Q_j, \forall j\in J \quad (25)$$

$$\sum_{p\in P} Q_{ip} = Q_i, \forall i\in I \quad (26)$$

$$X_j = \left\lceil\frac{Q_j}{pp}\right\rceil, \forall j\in J \quad (27)$$

$$X_i = \left\lceil\frac{Q_i}{pp}\right\rceil, \forall i\in I \quad (28)$$

$$U_j^n \in \{0,1\}, \forall j\in J, \forall n\in N_j \quad (29)$$

$$Y_{jk} \in \{0,1\}, \forall j\in J, \forall k\in J \quad (30)$$

$$R_{klv} \in \{0,1\}, \forall k,l\in M, \forall v\in V \quad (31)$$

$$G_{ijp} \in \{0,1\}, \forall p\in P, \forall j\in J, \forall i\in I \quad (32)$$

$$M_{kv} \ge 0, \forall k\in K, \forall v\in V \quad (33)$$

$$Q_{ip}, Q_{jp}, Q_{kp} \ge 0, \forall p\in P, \forall i\in I, \quad \forall j\in J, \forall k\in K \quad (34)$$

$$T > 0 \quad (35)$$

$$E, Z, NP_{jp}, NP_{kp} \geq 1, E, Z, NP_{jp}, NP_{kp} \in \text{int}, \quad (36)$$
$$\forall j \in J, \forall k \in K, \forall p \in P$$

Equation (1) is the objective function that minimizes total cost which is the sum of fixed cost for opening and operating UCC, routing cost, and expected inventory costs. The main difference between the proposed model and Saragih et al. (2017) is at Constraints (24)–(26) which the constraints to calculate the total lot size at retailers, UCCs, and suppliers respectively.

Constraints (2) ensure that each retailer is placed on exactly one vehicle route. Constraints (3) are the vehicle capacity constraints. Constraints (4) are the subtour elimination constraints. Constraints (5) are flow conservation constraints. Constraints (6) ensure that only one UCC is included in each route. Constraints (7) link the allocation and the routing components of the model. Constraints (8) ensure that each UCC can be assigned to only one capacity level. Constraints (9) are the capacity constraints associated with the UCCs.

Constraints (10) ensure that demand of a UCC for every product is the sum of the retailers' demands allocated to it. Constraints (11) ensure that a retailer is allocated exactly once to a UCC. Constraints (12) makes a supplier can supply more than one UCC for one product. Constraints (13) ensure that demand of a UCC for every product is fulfilled. Constraints (14) ensure that demand of a supplier for every product is amount of products sent from the supplier. Constraints (15) ensure that the amount of products sent from the supplier do not exceed the capacity.

Equations (16)-(17) are the formulation to calculate safety stock and number of shortage at retailers respectively. Equations (18)-(20) are the formulation to calculate reorder point at retailers, UCCs, and supplier respectively. Constraints (21) are single cycle time constraints. Constraints (22)-(23) are order frequency constraints at retailers and UCCs respectively. Constraints (27)-(28) are the formulation to calculate the number of trucks at UCCs and suppliers respectively. Constraints (29)-(36) represent the decision variables constraints.

4. Numerical examples

The proposed model is solved using LINGO 12 to obtain optimal solution. Three numerical examples are conducted to test the proposed model. This testing aims to evaluate the solution resulted from the proposed model so it can be known whether the proposed model results or does not result logical solution. Data used in the numerical examples are hypothetical data. The hypothetical data of the numerical examples are given in the Appendix.

4.1 Numerical example 1

Numerical example 1 consists of 4 retailers, 2 UCCs, 2 suppliers, and 2 products. The illustration of the solution of numerical example 1 is given in Figure 2. As it can be seen from Figure 2 that only one UCC is opened which is UCC 1. Both of the suppliers then supply the opened UCC which is UCC1 for product 1 and product 1. Closed UCC which is UCC 2 is not supplied by any suppliers.

All the retailers are supplied by the opened UCC which is UCC 1 according to their lot sizes for every product. The closed UCC does not supply any retailers. Vehicle routes are formed from UCC1 to serve retailers. It can be seen from Figure 2 that there are two tour formed to serve all the retailers. The vehicle routes for tour 1 is UCC1–R3–R4–UCC1 and the vehicle routes for tour 2 is UCC1–R6–R5–UCC1. Vehicle route is formed only from opened UCC.

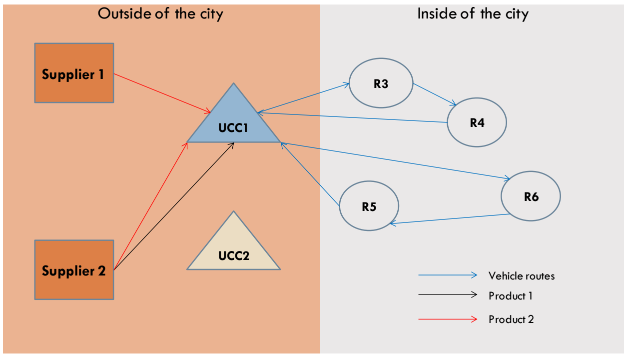

Figure 2. The illustration of solution for numerical example 1

From the solution of numerical example 1, it can be concluded that the proposed model results logical solution.

4.2 Numerical example 2

Numerical example 2 consists of 4 retailers, 2 UCCs, 3 suppliers, and 2 products. Figure 3 shows the illustration of the solution of numerical example 2. As it can be seen from Figure 3 that although there are 3 suppliers, the opened UCC is still one which is UCC 1. This is because the opened UCCs are affected only by the retailers' demands. If the capacity of one UCC is enough to fulfil all the demands then only one UCC opened. Opened UCC which is UCC 1 is supplied by all the suppliers and then supplies all retailers. Similar to numerical example 1, vehicle routes are formed only from opened UCC to deliver the lot sizes of the retailers for every product.

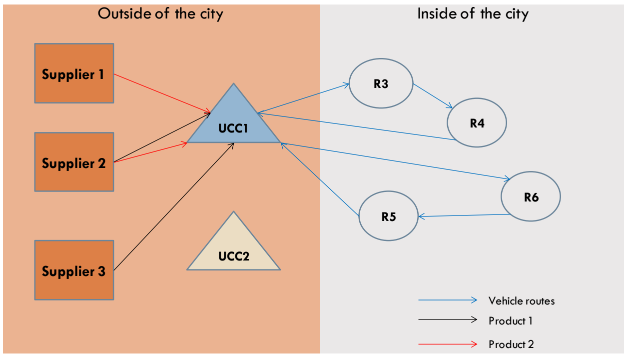

Figure 3. The illustration of solution for numerical example 2

From the solution of numerical example 2, it can be concluded that the proposed model results logical solution.

4.2 Numerical example 3

Numerical example 3 consists of 4 retailers, 3 UCCs, 3 suppliers, and 2 products. The illustration of the solution of numerical example 3 is given in Figure 4. Similar to numerical example 1 and numerical example 2, only one UCC opened which is UCC 1. This opened UCC is supplied by all suppliers and supplies all retailers. From UCC 1 is then formed vehicle routes to serve all the retailers.

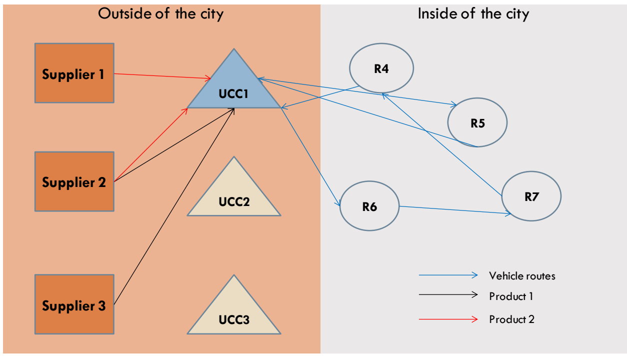

Figure 4. The illustration of solution for numerical example 3

From the solution of numerical example 3, it can be concluded that the proposed model results logical solution.

5. Conclusions

This paper has developed single-tier city logistics model for multi products. The proposed model has never been developed before. This paper also considers traffic congestion in the model which is presented as the marginal external congestion cost parameter that emerges in the routing cost. This makes the proposed model more represents the real system in a city.

The proposed model is solved using LINGO 12 to obtain optimal solution. From three numerical examples that has been conducted, the proposed model results logical solution.

The problems adressed in this paper are NP-hard problem ([6]), so it gives challenge to develop a heuristic method to solve the problem in large scale data for future work.

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Appendix A. Data for Numerical example 1

Table 1. The values of parameter for retailers of numerical example 1

Retailer/ Product	μ_{kp} (Kg/Day)		σ^2_{kp} (Kg/Day)		a_{kp} (Rp/order)		h_{kp} (Rp/Kg/period)		s_{kp} (Rp/Kg)		lt_{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. The values of parameter for UCCs of numerical example 1

UCC/Product	b_j^n (Kg/Day)		f_j^n (Rp/Day)		a_{jp} (Rp/order)		h_{jp} (Rp/Kg/period)		lt_{jp} (Day)		vc (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. The values of parameter for suppliers of numerical example 1

Supplier/Product	b_{ip} (Kg/Day)		a_{ip} (Rp/order)		h_{ip} (Rp/Kg/period)		lt_{ip} (Day)		w (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. The values of distance and transportation cost of numerical example 1

Node	d_{kl} (Km)						ca (Rp/Km)
	1	2	3	4	5	6	
1	0	3	2	1	5	4	1
2	3	0	4	2	3	1	
3	2	4	0	5	2	1	
4	1	2	5	0	2	1	
5	5	3	2	2	0	4	
6	4	1	1	1	4	0	

Table 5. The values of time loss and value of time of numerical example 1

Node	t_{kl} (Hour)						cb (Rp/Hour)
	1	2	3	4	5	6	
1	0	3	4	5	1	2	1.5
2	3	0	2	4	3	5	
3	4	2	0	1	4	5	
4	5	4	1	0	4	5	
5	1	3	4	4	0	2	
6	2	5	5	5	2	0	

Appendix B. Data for Numerical example 2

Table 6. The values of parameter for retailers of numerical example 2

Retailer/ Product	μ_{kp} (Kg/Day)		σ^2_{kp} (Kg/Day)		a_{kp} (Rp/order)		h_{kp} (Rp/Kg/period)		s_{kp} (Rp/Kg)		lt_{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 7. The values of parameter for UCCs of numerical example 2

UCC/Product	b^n_j (Kg/Day)		f^n_j (Rp/Day)		a_{jp} (Rp/order)		h_{jp} (Rp/Kg/period)		lt_{jp} (Day)		vc (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 8. The values of parameter for suppliers of numerical example 2

Supplier/Product	b_{ip} (Kg/Day)		a_{ip} (Rp/order)		h_{ip} (Rp/Kg/period)		lt_{ip} (Day)		w (Kg)
	1	2	1	2	1	2	1	2	
1	0	60	12	6	8	4	0.5	0.25	60
2	50	60	6	6	4	4	0.25	0.25	
3	50	0	6	12	4	8	0.25	0.5	

Table 9. The values of distance and transportation cost of numerical example 2

Node	d_{kl} (Km)						ca (Rp/Km)
	1	2	3	4	5	6	
1	0	3	2	1	5	4	1
2	3	0	4	2	3	1	
3	2	4	0	5	2	1	
4	1	2	5	0	2	1	
5	5	3	2	2	0	4	
6	4	1	1	1	4	0	

Table 10. The values of time loss and value of time of numerical example 2

Node	t_{kl} (Hour)						cb (Rp/Hour)
	1	2	3	4	5	6	
1	0	3	4	5	1	2	1.5
2	3	0	2	4	3	5	
3	4	2	0	1	4	5	
4	5	4	1	0	4	5	
5	1	3	4	4	0	2	
6	2	5	5	5	2	0	

Appendix C. Data for Numerical example 3

Table 11. The values of parameter for retailers of numerical example 3

Retailer/ Product	μ_{kp} (Kg/Day)		σ^2_{kp} (Kg/Day)		a_{kp} (Rp/order)		h_{kp} (Rp/Kg/period)		s_{kp} (Rp/Kg)		lt_{kp} (Day)	
	1	2	1	2	1	2	1	2	1	2	1	2
4	10	15	2	2	4	4	2	2	1	1	0.25	0.25
5	20	25	3	3	4	4	2	2	1	1	0.25	0.25
6	30	35	4	4	4	4	2	2	1	1	0.25	0.25
7	40	45	5	5	4	4	2	2	1	1	0.25	0.25

Table 12. The values of parameter for UCCs of numerical example 3

UCC/Product	b^n_j (Kg/Day)		f^n_j (Rp/Day)		a_{jp} (Rp/order)		h_{jp} (Rp/Kg/period)		lt_{jp} (Day)		vc (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	
3	400	400	300	300	5	5	3	3	0.25	0.25	

Table 13. The values of parameter for suppliers of numerical example 3

Supplier/Product	b_{ip} (Kg/Day)		a_{ip} (Rp/order)		h_{ip} (Rp/Kg/period)		lt_{ip} (Day)		w (Kg)
	1	2	1	2	1	2	1	2	
1	0	60	12	6	8	4	0.5	0.25	60
2	50	60	6	6	4	4	0.25	0.25	
3	50	0	6	12	4	8	0.25	0.5	

Table 14. The values of distance and transportation cost of numerical example 3

Node	d_{kl} (Km)							ca (Rp/Km)
	1	2	3	4	5	6	7	
1	0	3	2	1	5	4	2	1
2	3	0	4	2	3	1	5	
3	2	4	0	5	2	1	3	
4	1	2	5	0	2	1	4	
5	5	3	2	2	0	4	1	
6	4	1	1	1	4	0	5	
7	2	5	3	4	1	5	0	

Table 15. The values of time loss and value of time of numerical example 3

Node	t_{kl} (Hour)							cb (Rp/Hour)
	1	2	3	4	5	6	7	
1	0	3	4	5	1	2	4	1.5
2	3	0	2	4	3	5	1	
3	4	2	0	1	4	5	3	
4	5	4	1	0	4	5	2	
5	1	3	4	4	0	2	5	
6	2	5	5	5	2	0	1	
7	4	1	3	2	5	1	0	