A Multiobjective Programming for Transportation Problem with the Consideration of both Depot to Customer and Customer to Customer Relationships

Wuttinan Nunkaew and Busaba Phruksaphanrat

Abstract— **A multiobjective programming for transportation model with the consideration of both depot to customer and customer to customer relationships is proposed in this research. The objectives are to minimize the total transportation cost which is the baseline objective and to minimize the overall independence value. A Lexicographic Goal Programming (LGP) is applied to the proposed model. A minimization of the total transportation cost is set to the first goal and a minimization of the overall independence value is set to the second goal of the proposed model. This model can obtain the better result than a single objective transportation model with a minimization of the total transportation cost objective. That is because the depot to customer relationship is considered in the first priority to get the lowest cost and the vicinity of customers in the same depot is concerned in the second priority to group near by customers to be served in the same depot if the capacity of the depot is sufficient. Moreover, each customer can be served by only one depot. These advantages are more compatible to the reality than conventional transportation model.**

Index Terms—**Customer to Customer relationship, Lexicographic Goal Programming, Multiobjective programming, Transportation Problem**

I. Introduction

In general, distribution of product from depot to customer is called "Transportation Problem" (TP) which first developed by F. L. Hitchcock since 1941 [1], [2]. It usually aims to minimize the total transportation cost [3]-[7]. Other objectives that can be set are a minimization of the total delivery time, a maximization of the profit, etc [8]-[11]. From the investigation, the entire existing objectives in single objective transportation models are represented by quantitative information. This may cause the negligence of some crucial points which can not be described by quantitative data [12], [13].

In reality, considering only one objective is not sufficient because it may not lead to the practical optimal solution. Thus, the Decision Makers (DMs) are rather to pay attention on several objectives at the same time. This is a characteristic of a multiobjective transportation model [1], [8], [14]-[16].

The multiobjective transportation model is set to solve the transportation problem simultaneously associated with several objectives. Normally, existing multiobjective transportation models use a minimization of the total cost objective as one of their objectives. The other objectives may concern about quantity of goods delivered, underused capacity, energy consumption, total delivery time, etc [8], [14], [17], [18]. These objectives consider mainly on depot to customer relationship.

An efficient method for the alternative warehouse network evaluation and supply chain design was proposed by J. Korpela *et al.* [13], [19], [20]. This method bases on Analytic Hierarchy Process (AHP) and Mixed Integer Programming (MIP) integration. The maximization objective of the total customer's preference value based on the customer's viewpoint is applied instead of a minimization objective of the total cost. This condition refers to customer to depot relationship consideration.

However, the consideration of the relationship between customer and customer is also critical because in fact vehicle route for each depot does not move from depot to customer and returns back from customer to depot as in the transportation model, it moves from depot to customer and moves forward to the other customers. So, it needs also to consider customer to customer relationship. Moreover, the qualitative information about transportation problem should also be considered. We can evaluate these qualitative data by several methods such as the pairwise comparison, scale evaluation, and using linguistic variables [12], [21]-[23].

In this research, we propose a multiobjective programming for transportation problem with the depot to customer and the customer to customer relationship considerations that contains both quantitative and qualitative data.

The remainder of this paper is organized as follows. The conventional transportation problem and its mathematical model are discussed in Section II. Then, it is followed by the model formulation in Section III. Detail discussion of customer to customer relationship is contained in Section IV. Next, a numerical example is illustrated in Section V. Results and discussions are in Section VI. Finally, the conclusion of this research is provided in Section VII of this research.

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II. Transportation Problem

The Transportation Problem (TP) was first developed and proposed by F. L. Hitchcock since 1941. The classical transportation problem is referred to a special case of Linear Programming (LP) problem and its model is applied to determine an optimal solution of delivery available amount of satisfied demand in which the total transportation cost is minimized. The transportation problem network form can be shown as in Fig.1.

The following notation is used.

Index sets:

i index for depot, for all $i=1,2,\ldots,M$.
j index for customer, for all $j=1,2,\ldots,N$.
l index for customer, for all $l=1,2,\ldots,N$.
k index for objective, for all $k=1,2,\ldots,K$.
t index for goal, for all $t=1,2,\ldots,T$.

Decision variables:

x_{ij} is 1 if customer j is served by depot i and 0, otherwise.
ρ_t is the positive deviation or overachievement of goal t.
η_t is the negative deviation or underachievement of goal t.

Parameters:

a_i is the capacity of depot i.
b_j is the demand of each customer j.
c_{ij} is the unit transportation cost delivered from depot i to customer j.
y_{ij} is an amount of demand transported from depot i to customer j.
τ_t is the specified target for goal t.
R_{lj} is the relationship value between customer l and j.
R_{max} is the maximum scale of the relationship value which is assigned to 9.
R'_{lj} is the independence value between customer l and j. $R'_{lj} = R_{max} - R_{lj}$.

The baseline model for transportation problem can be shown as follows [2], [9], [10], [24]-[27],

$$\min\ f(y) = \sum_i^M \sum_j^N c_{ij}\, y_{ij}\,, \tag{1}$$

subject to

$$\sum_j^N y_{ij} \le a_i\,, \qquad \text{for all } i. \tag{2}$$

$$\sum_i^M y_{ij} = b_j\,, \qquad \text{for all } j. \tag{3}$$

$$\sum_i^M a_i = \sum_j^N b_j\,, \tag{4}$$

$$y_{ij} \ge 0, \qquad \text{for all } i \text{ and } j. \tag{5}$$

Equation (1) is the objective function of the transportation model that is to minimize the total transportation cost. The total served demand of each depot must be less than or equal to the available supply as shown in (2). Equation (3) represents that the sum of received demand of each customer must be equal to its demand. Equation (4) shows that the sum of available supply of all depots must be equal to the sum of all demand. Equation (5) represents non-negativity constraint.

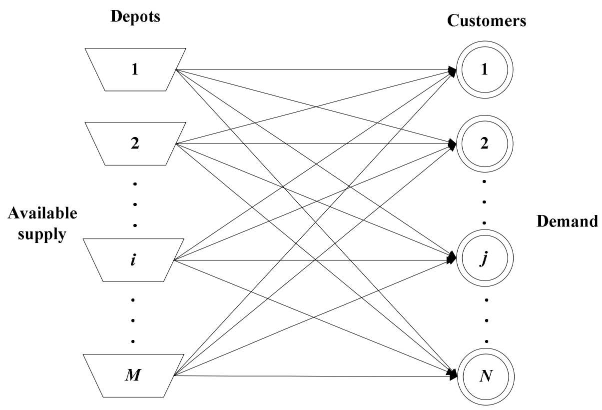

Fig.1 The Transportation Problem Network

The earlier presented model is a single objective transportation problem, which is extensively used. For the problem associated with more than one objective, the decision maker need to simultaneously take other objectives apart from the minimization objective of transportation cost .The other objectives for transportation problem may related to delivery time, quantity of goods delivered, unfulfilled demand, underused capacity, reliability of delivery, safety of delivery, etc. The multiobjective transportation model with k objectives can be represented as [8]

$$\min\ f_1(y) = \sum_i^M \sum_j^N c_{ij}^1\, y_{ij}\,,$$

$$\vdots$$

$$\min\ f_K(y) = \sum_i^M \sum_j^N c_{ij}^K\, y_{ij}\,,$$

subject to

$$\sum_j^N y_{ij} \le a_i\,, \qquad \text{for all } i.$$

$$\sum_i^M y_{ij} = b_j\,, \qquad \text{for all } j.$$

$$\sum_i^M a_i = \sum_j^N b_j\,,$$

$$y_{ij} \ge 0, \qquad \text{for all } i \text{ and } j.$$

where c_{ij}^k represent the coefficients related to y_{ij} variable for objective k.

There are many researchers adapting this model for their computational researches [1], [4], [14], [17], [18], [28]. However, in these existing transportation models the demand for a customer may be served by multiple depots, which is not reasonable and not satisfied by customers. Thus, the zero-one integer programming should be integrated into the transportation model for enforcing that each customer can solely receive all requested demand from only one depot if the capacity is sufficient. Moreover, both existing single and multiple objective models focus only on the depot to customer relationship consideration. This kind of relationship can be derived in a quantitative form.

In the research work of J. Korpela *et al.* [13], [19], [20], the total customer's preference value in a warehouse network and supply chain design objective is maximized, instead of a minimization objective of the total cost, using the integration of AHP and MIP. A preference value for each alternative depot is obtained from each customer's perspective. It is derived in quantitative and qualitative forms based on customer's viewpoint and refers to customer to depot relationship consideration.

In case of two or more customers that need to be served by the same depot e.g., customer A and B are subsidiary companies of the same headquarter, the existing models cannot support this situation. It is a result of lacking of customer to customer relationship consideration.

For illustration, Fig.2 (a) depicts the location layout of the supposed system. In depot to customer relationship consideration of a transportation problem e.g., minimization of the total transportation cost, customers A and B certainly are closer to depot D1 than depot D2. Similarly, customers E, F, G, and H are closer to depot D2 than depot D1. It can properly assign the customers to be served by each depot as shown in Fig.2 (b). Customer C is possible to be assigned to depot D1 or depot D2. There is no significant difference between assigning customer C to depot D1 and depot D2 for cost aspect because they are assumed to have the same distance. But, we can clearly observe that customer C should be assigned to depot D1 because customer C is in the vicinity of customers A and B which are assigned to be served by depot D1. It means that customer to customer relationship consideration is also necessary for a transportation problem. Fig.2 (c) shows both considerations of depot to customer and customer to customer relationships for the transportation problem. These two relationships lead to the better and more appropriate solution. Hence, in this research, both determinations of depot to customer and customer to customer relationships are in concern.

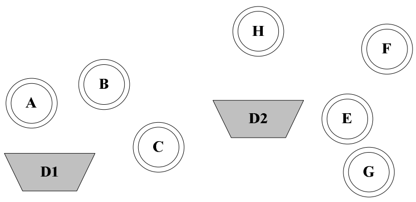

Fig.2 (a) The location layout of the supposed system

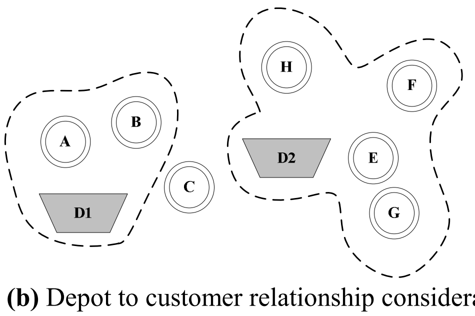

Fig.2 (b) Depot to customer relationship consideration

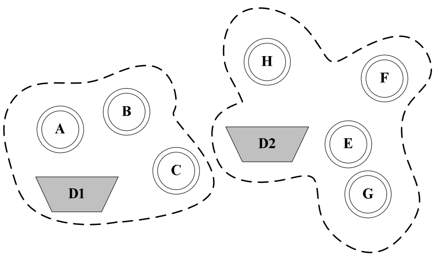

Fig.2 (c) Depot to customer and customer to customer relationship consideration

Next, we will demonstrate the way to develop a model which supports customer to customer consideration but still cover the conventional approach which based on depot to customer relationship consideration.

III. MODEL FORMULATION

Most of existing research works of a transportation problem has considered depot to customer relationship. However, the relationship between customer and customer is also critical because in fact vehicle route for each depot does not move from depot to customer and returns back from customer to depot as in the transportation model, it moves from depot to customer and moves forward to the other customers. So, it needs also to consider customer to customer relationship to obtain the neighborhood customers.

Then, two objectives are concerned. The first objective is to minimize the total transportation cost which is the baseline objective for all transportation models. It is the depot to customer relationship consideration using quantitative data. The second objective is to minimize the overall independence value between customer and customer, which means the consideration of customer to customer relationship. This problem is called multiobjective problem.

To solve a multiobjective problem, there are several methods used in general e.g., Goal Programming (GP) [3], [8], [29]-[34], Fuzzy Linear Programming (FLP) [1], [15]-[18], [28], [35], [36], Compromise Programming (CP) [8], [32], etc. In this research, goal programming is chosen because of its simplicity, popularity and ease to understand.

The goal programming comprises of two well-known methods i.e., Weighted Goal Programming (WGP) and Lexicographic Goal Programming (LGP). For WGP, the difficulty is how to assign appropriate weight to each goal. In the LGP method, the goals are satisfied according to a lexicographic order, the highest preemptive priority goal will be satisfied first. Then, the remaining priority will be optimized accordingly. Thus, the LGP has been chosen to formulate this problem. Moreover, in a transportation problem the demand for a customer should be served by only one depot if the capacity of one depot is sufficient but the conventional model does not considered this condition. So it is included in the constraint of the proposed method.

A. Objective functions

The First Objective Function: To minimize the total transportation cost

$$\min \ f_1(x) = \sum_{i}^{M}\sum_{j}^{N} c_{ij} x_{ij} b_j \ . \qquad (6)$$

This first objective function is similar to a conventional transportation model that is to minimize the total transportation cost, which reflects the depot to customer relationship consideration. A zero-one integer programming is integrated into transportation model for enforcing that each customer can solely receive all demand from only one depot.

The Second Objective Function: To minimize the overall independence value between customer and customer

R_{lj} is the relationship value of customer to customer. It means the value that indicates the interrelationship between two customers. It may be derived from qualitative or quantitative values such as the distance, business relations and managerial convenience. Customer to customer relationship can be evaluated by using the pairwise comparison matrix. Afterwards, this matrix is converted to the independence value for each pair of customers. The detail of this approach is explained in the following section. Then, R'_{lj} can be calculated from $R'_{lj} = R_{max} - R_{lj}$.

The overall independence value of customer l with the other customers, $j=1, 2, \ldots, N$ in depot i can be represented by

$$Q_{il} = \sum_{j}^{N} x_{ij} R'_{lj}, \qquad \text{for all } i \text{ and } l. \qquad (7)$$

Then, the overall independence value for all customers with the other customers, $j=1, 2, \ldots, N$ in the same depot can be represented by

$$\sum_{i}^{M}\sum_{j}^{N} Q_{il}\, x_{ij}, \qquad \text{where } l=j.$$

So, the second objective function is

$$\min\ f_2(x) = \sum_{i}^{M}\sum_{j}^{N} Q_{il}\, x_{ij}. \qquad (8)$$

Equation (8) is developed on the basis of the adjacency score that commonly use for defining the relationship value between departments in a facility planning problem which was presented by J. A. Tompkins *et al.* (2003) [37], [38].

B. Goal programming model

According to two objectives above, two goal functions can be derived as follows:

$$f_1(x) - \rho_1 + \eta_1 = \tau_1, \qquad (9)$$

$$f_2(x) - \rho_2 + \eta_2 = \tau_2. \qquad (10)$$

Equation (9) is the goal function of the first objective and (10) is the goal function of the second objective [32]-[34].

The objective function of the lexicographic goal programming in order to minimize the deviation of the target transportation cost and the deviation of the target overall independence value can be shown as,

$$\text{lex min} = \left[(\rho_1 + \eta_1), (\rho_2 + \eta_2)\right], \qquad (11)$$

subject to

$$\sum_{i}^{M}\sum_{j}^{N} c_{ij} x_{ij} b_j - \rho_1 + \eta_1 = \tau_1, \qquad (12)$$

$$\sum_{i}^{M}\sum_{j}^{N} Q_{il}\, x_{ij} - \rho_2 + \eta_2 = \tau_2, \quad \text{where } l=j. \qquad (13)$$

$$\sum_{i}^{M} x_{ij} = 1, \qquad \text{for all } j. \qquad (14)$$

$$\sum_{j}^{N} x_{ij}\, b_j \le a_i, \qquad \text{for all } i. \qquad (15)$$

$$x_{ij}, \rho_t, \eta_t \ge 0, \qquad \text{for all } i, j, \text{ and } t. \qquad (16)$$

Constraints (12) and (13) are goal constraints. Constraint (14) is added to ensure that each customer must be served by only one depot. Constraint (15) ensures that the capacity of each depot is not exceeded, whereas (16) is a non-negative constraint.

IV. A Customer to Customer Relationship Consideration

Such mentioned previously, a customer to customer relationship is necessary to be considered in the transportation model. The customer to customer relationship (R_{lj}) between customer l and j is allocated based on 1-9 Saaty's scale [22], [23] in the pairwise comparison matrix. Table I shows the modified 1-9 Saaty's scale, used for assigning customer to customer relationship value.

In general, 1-9 Saaty's scale using in the Analytic Hierarchy Process (AHP) is used to define the comparative priority. It is an effective decision tool and applicable for both quantitative and qualitative data. The upper triangular matrix and the lower triangular matrix in AHP are reciprocal value that is $R_{lj} = \frac{1}{R_{jl}}$. But in this research, we emphasize on a relationship value not a priority value, so $R_{lj} = R_{jl}$ is assigned. The elements in a diagonal of a matrix are relationship values of comparing itself, so it is denoted by the maximum scale of the relationship value (R_{max}). An example of relationship rating in a pairwise comparison matrix is given as Table II.

In the next section, a numerical example will be illustrated.

V. A Numerical Example

In order to demonstrate the application of the proposed model, a simple problem with two depots and ten customers is given on the assumption that each customer must be served all demand by only one depot. Moreover, a depot's capacity is sufficient to serve a customer. The list of the basic data for the particular example is shown in Table III. Fig.3 depicts the location map, which we can presume the anticipated solution by quantitative data (the distance between depot and customer) in depot to customer relationship consideration that customers C1, C2, C3, and C4 should be assigned by depot D1 and customer C7, C8, C9, and C10 should be assigned by depot D2, whereas customer C5 and C6 may be assigned by depot D1 or D2.

Table I The modified 1-9 Saaty's scale

Scale	R_{lj}
Low Relation	1
Medium Low Relation	3
Medium Relation	5
Demonstrated Relation	7
Extreme Relation	9
Compromise Value	2,4,6,8

Table II An example of relationship rating

	C1	C2	C3	C4	C5
C1	9	7	9	3	1
C2	7	9	7	1	1
C3	9	7	9	5	5
C4	3	1	5	9	9
C5	1	1	5	9	9

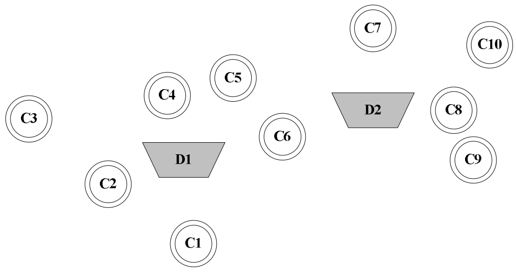

Fig.3 The location map of the particular example

Table III Transportation cost per unit (in U.S. dollar) and customer demand

Customer j	Depot i c_{ij} (transportation cost per unit)		Demand b_j (unit)
	D1	D2	
C1	10	35	500
C2	15	35	250
C3	12.5	30	300
C4	20	35	750
C5	15	15	280
C6	10	10	370
C7	30	14	450
C8	35	15	650
C9	30	10	1000
C10	40	15	250
Available supply a_i (unit)	3000	3000	

Table IV A pairwise comparison matrix of the customer to customer relationship value

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	9	8	7	7	5	5	3	2	2	1
C2	8	9	8	7	7	5	3	3	2	1
C3	7	8	9	8	7	5	2	1	1	1
C4	7	7	8	9	9	7	3	1	1	1
C5	5	7	7	9	9	9	3	1	1	1
C6	5	5	5	7	9	9	3	1	1	1
C7	3	3	2	3	3	3	9	7	5	8
C8	2	3	1	1	1	1	7	9	9	7
C9	2	2	1	1	1	1	5	9	9	7
C10	1	1	1	1	1	1	8	7	7	9

To apply the proposed model in this example, we firstly evaluate the relationship between customer and customer by rating scale as in Table IV. The mathematical expression for this problem can be shown as follows,

$$\text{lex min}=\left[(\rho_1+\eta_1),(\rho_2+\eta_2)\right],$$

subject to

$$\sum_{i}^{2}\sum_{j}^{10} c_{ij}x_{ij}b_j - \rho_1 + \eta_1 = 65{,}200\ ,$$

$$\sum_{i}^{2}\sum_{j}^{10} Q_{il}\, x_{ij} - \rho_2 + \eta_2 = 84\ , \qquad \text{where } l=j.$$

$$\sum_{i}^{2} x_{ij} = 1\ , \qquad \text{for all } j.$$

$$\sum_{j}^{10} x_{ij}\, b_j \le a_i\ , \qquad \text{for all } i.$$

$$x_{ij}, \rho_t, \eta_t \ge 0\ , \qquad \text{for all } i, j, \text{and } t.$$

In this example, we set the goal targets (τ_1, τ_2) by using aspiration level of each objective function. The possible results of the proposed model when the first priority is optimized are shown in Tables V (a)-V (d). There are four solutions. These solutions are identical with the single objective optimization problem that has a minimization of total transportation cost as an objective. Obtained results of the total transportation cost are the same, which is $65,200.

After optimizing the second priority, the optimal solution is gained as shown in Table VI with the total transportation of $65,200 and the overall independence value of 84. This is the best solution from all possible solutions. It can be reached by using our proposed model. It is an assignment of each customer to each depot in order to satisfy the both goals.

Table VII shows all of results for both goals at each stage. The positive deviations of both goals are zero resulting from minimization of LGP which means that both targets can be reached.

VI. Results And Discussions

From illustration, there are four possible solutions from the single objective transportation problem with a minimization objective of the total transportation cost. These solutions have

Table V (a) A possible solution of the first priority: case a

Depot	Customer
D1	C1, C2, C3, C4
D2	C5, C6, C7, C8, C9, C10

Table V (b) A possible solution of the first priority: case b

Depot	Customer
D1	C1, C2, C3, C4, C5
D2	C6, C7, C8, C9, C10

Table V (c) A possible solution of the first priority: case c

Depot	Customer
D1	C1, C2, C3, C4, C6
D2	C5, C7, C8, C9, C10

Table V (d) A possible solution of the first priority: case d

Depot	Customer
D1	C1, C2, C3, C4, C5, C6
D2	C7, C8, C9, C10

Table VI The solution after optimizing the second priority

Depot	Customer
D1	C1, C2, C3, C4, C5, C6
D2	C7, C8, C9, C10

Table VII Results from LGP of the proposed model

	Goal	
	1	2
Target	$ 65,200	84
Objective value in the first priority	$ 65,200 $ 65,200 $ 65,200 $ 65,200	160 (case a) 116 (case b) 128 (case c) 84 (case d)
Objective value after optimizing the second priority	$ 65,200	84
Positive deviation of each goal	0	0

the same as the results of the first priority of our proposed model. Some solutions may have high independence values (less relationship among customers which should be served by the same depot), which means that the customers for each depot may not locate in the same area. The single objective optimization contains only quantitative data. It can serve only depot to customer relationship consideration but omit customer to customer relationship consideration. Meanwhile, after performing the second priority optimization of our proposed model, the lowest cost and the lowest independence value alternative can be obtained. That means the lowest total transportation cost and the nearest vicinity of customers are determined. Moreover, each customer can be served by only one depot if the capacity of the depot is sufficient. The proposed model combines consideration of both depot to customer and customer to customer relationships. Both quantitative and qualitative data are included in the model.

VII. Conclusion

Owing to lack of qualitative or intangible consideration especially the customer to customer relationship in a conventional transportation problem, the multiobjective programming for transportation problem with the consideration of depot to customer and customer to customer relationships is developed. LGP is chosen to solve the multiobjective transportation problem with a minimization of the total transportation cost and the overall independence value. The proposed model can obtain the efficient reasonable solution that satisfied both considerations of depot to customer and customer to customer relationship that means the lowest total transportation cost and the nearest vicinity of customers are determined. Moreover, each customer can be served by only one depot if the capacity of the depot is sufficient. These advantages are more compatible to the reality than conventional transportation model.

For further researches, the proposed model should be applied to the practical real world applications and it should be improved for the remaining assumptions.

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