A MULTI-OBJECTIVE MODEL FOR DESIGNING A GLOBAL SUPPLY CHAIN
NETWORK WITH INTERNATIONAL TRANSPORTATION MODE SELECTION:
FORMULATION AND ANALYSIS

Ashkan Hafezalkotob
Department of Industrial Engineering
Iran University of Science and Technology (IUST), Tehran
Hafezalkotob@iust.ac.ir

Ebrahim Teimoury
Davood Mohammadytabar
Mehdi Ahmadi
Department of Industrial Engineering
Iran University of Science and Technology (IUST), Tehran
Teimoury@iust.ac.ir
davood_mohammadytabar@yahoo.com
m_ahmadi@ie.sharif.edu

ABSTRACT
Cost or profit optimization is the most widely used method for designing a supply chain network, but real world supply chain has multiple attributes. In the most supply chain network design models, these attributes driven by operational dynamics such as lead times have seldom been considered. This paper develops a network design model that considers lead times of different international transportation modes in a global supply chain as an objective function. Therefore, the proposed model minimizes transportation and location costs, and transportation times concurrently. The model allows for multiple levels of capacities available to the warehouses and plants. The use of different capacity levels makes the problem more realistic. At the end, we use weighted \( L_p \)-metrics method to produce Pareto frontier optimal solutions. It provides more control for decision makers on determination of the optimization solution, and presents more information for better insight into the supply chain configuration. The results show that the proposed model is reliable and robust.

KEYWORDS
Global Supply Chain Design, Lead time, Transportation Modes, Weighted \( L_p \)-metrics, Pareto Frontier.

1. INTRODUCTION

1.1. Global supply chain
The last decades of the twentieth century witnessed a considerable expansion of supply chains into international locations, especially in automobile, computer, and apparel industries (Taylor, D., 1997; Dornier, P.P. et al., 1998). Increased competition, rising customer expectations for product value, the growth of product variety, and convergence of customer tastes in disparate geographical regions have considered with adoption of a new competitive strategy on the part of multinational companies (Cohen, M.A. and Mallik, S., 1997).

There are many forces driving firms to enter the international arena. These forces serve as both motivators and facilitators. Enterprises are motivated to expand global operation to grow and survive. Global operations are also facilitated through developing technology, and capabilities. The five forces driving global operations are economic growth, supply chain perspective, regionalization, technology and deregulation (Bowersox, D.J. and Closs, D.J., 1996). While many forces facilitate borderless operations, some significant barriers continue to impede global supply chain. International company encounters barriers such as pricing and marketing, competition, tariffs and trade restrictions, institutional infrastructures, supplier considerations, transportation systems and long distance problems,
diversity in culture and so on. Practitioners are well advised to factor these risks into decision while designing global supply chain (Meixell, M.J and Gargeya, V.B., 2005). In fact, Management must balance the cost of overcoming these barriers with potential benefits of international trade to achieve the actual benefits of successful international operations (Bowersox, D.J and Closs, D.J., 1996).

The global supply chain approach can leverage use of supply chain assets beyond the factory and the design group, e.g., in procurement, distribution, and after-sales services. The total effect is to minimize the landed cost of products delivered to each market segment at each market location, while maintaining a high level customer services for product availability and system responsiveness, all of which lead to customer satisfaction through life cycle of ownership (Cohen, M.A., and Mallik, S., 1997).

1.2. Global supply chain design

Global corporations face the continuing challenge to constantly evaluate and configure their production and distribution systems and strategies to desired customer service at the lowest possible cost while maximizing their after tax profit (Goetschalckx M. et al., 2002).

A supply chain design problem comprises the decision regarding the number and location of production facilities, the amount of capacity at each facility, the assignment of market region to one or more locations, and supplier selection for subassemblies, components and materials (Chopra, S. and Meindle, P., 2004). Global supply chain design extends this definition to include selection of facilities at international location, and the special globalization factors this involves (Meixell, M.J and Gargeya, V.B., 2005). In other words, Global supply chain design components consist of: (1) a number of warehouses or packaging centers, (2) a number of manufacturing or assembling plants, (3) supplier of components and raw materials, (4) zero, one or more distribution centers, (5) customer zones and finally, (6) transportation channel that link above facilities in international area.

To date, much of the emphasis in supply chain management has been on cost reduction but performance in real world supply chain has multiple attributes. These attributes play even more important role in global supply chain network design because of long lead times and different transportation modes available in the international area. As defined in the supply chain operations reference (SCOR) model, performance is measured in terms of reliability, responsiveness, flexibility, cost, and assets (supply chain council, 2003). Different articles imply the role of improving quality, reducing cost, and schedule requirement as the objectives to global supply chain design. (Handfield, R.B., 1994; Hammond, J.H., 1990; Bowersox, D.J. and Closs, D.J., 1996; Bozarthet C. et al., 1998; Lowson, B. et al., 1999; Eskigun, E. et al., 2005).

Bozarthet C. et al. (1998) pointed out the importance of measuring delivery performance and quality in global supply chain management. In the most supply chain network design models, measures of customer satisfaction driven by the operational dynamics such as lead times have seldom been considered (Eskigun, E. et al., 2005).

1.3. Plan for this Research

This paper introduces a new model for designing a global supply chain network of an automotive company. Supply chain network, shown in Figure 1, consists of the main activities involved in packaging, transporting vehicle parts, and also in warehousing and assembling activities in other countries.

Main parts of vehicles are shipped from manufacturing plant to consolidation center. On the other hand, suppliers deliver other parts to this center. In the consolidation center, received parts are consolidated and packed as unit loads. Then, the unit loads are shipped to the warehouses in destination country using different international transportation modes. Each warehouse delivers shipments to the assembly plant. Finally, customer zones demands can be satisfied by these plants.
The performance-cycle length is the major difference between domestic and global operations. Instead of three- to five- day transit times and four- to ten-day total performance cycles, global operations often require performance cycles measured in terms of weeks or months. The reasons for a long performance cycle are communication delays, financing requirements, special packing requirements, ocean freight scheduling, long transportation times, and customs clearance. The combination and complexity of these activities cause international performance cycles to be longer, less consistent, and less flexible than those for typical domestic operations.

An important development in automotive industry in the recent years has been an increased interest in reducing the lead-time required to delivered vehicles from plants to customers (Eskigun E. et al, 2005). This paper considers lead times of different international transportation modes in global supply chain as an objective function. Therefore, the proposed model minimizes transportation and location costs and transportation time concurrently. Our integrated model, in addition to ascertain numbers, locations, and capacities of both warehouses and plants considers international transportation modes as variables to be determined in the model and develops at the same time the best strategy for shipping part from consolidation center to warehouse, from warehouses to plants and from plants to customer zone.

In this paper, we consider supply chain network design based on two important criteria; time and cost. One can categorize a supply chain, with regards to these two factors as follows:

- Effective supply chains: those that focus on a goal of producing and supplying at lowest possible.
- Responsive supply chains: those with a capability to respond customer needs including short lead times, high service level, large variety of products, and building highly innovative products.

Responsiveness, however comes at a cost. For instance, to respond to short lead times, more expensive transportation modes (like air transportation) should be utilized, which increases costs. In this research, lead time criterion is used for measuring the level of the supply chain responsiveness.

Specifying effectiveness and responsiveness of a supply chain is one of the strategic decisions, and it is a great challenge to consider these elements in the supply chain design model. Developing traditional single criterion models, this paper proposes a new model to consider trade offs between effectiveness and responsiveness in the supply chain design concurrently.
Usually, in the real world, there exist several capacity levels to choose from for each facility. Amiri (2006) introduced a model that considers different capacity levels for facilities. This research develops the model proposed by Amiri and integrates it with transportation mode decision with respect to lead times.

The reminder of this paper is organized as follows. We review previous related work in section 2. In section 3, a mathematical formulation of global supply chain design problem is presented. A case study and related information is provided in section 4. A solution procedure is used to solve the problem in section 5. A summary of the work presented in this paper is given in section 6.

2. LITERATURE REVIEW

Several literature reviews have been conducted on aspect of global supply chain design. These include Verter, V. and Dincer, M.C. (1992, 1995), Vidal, C.J. and Goetschalckx, M. (1999), Schmidt, G. and Wilhelm, W.E. (2000), Goetschalckx M. et al. (2002), Meixell, M.J. and Gargeya, V.B. (2005). Among these reviews, Meixell, M.J. and Gargeya, V.B. (2005) sought to assess how well models support global supply chain design decisions in light of globalization difficulties, outsourcing, Integration, and strategic alignment. They developed classification scheme that was focused on these practical considerations and carried out a structured review that provided a guide to earlier research on the subject of global supply chain design.

Amiri, A. (2006) introduced a production and distribution network design model that allowed for multiple levels of capacities available to warehouses and plants. The use of different capacity levels makes the problem more realistic. The model did not limit number of facilities to open to a pre-specified value. This paper proposed a lagrangian based solution procedure for the problem.

The potential benefits of lead-time reduction in supply chain management have been widely documented, and include responsiveness to market change, reduced pipeline inventory, and improved customer satisfaction (Eskigun E. et al, 2005). Eskigun E. et al. (2005) developed the design of an outbound supply chain network considering lead times, location of distribution facilities, and choice of transportation modes. Their two echelon- model only considered two different transportation modes in whole supply chain. Therefore, it was not flexible enough to plan different transportation modes for each facility. In addition, only one level of capacity was considered for the vehicle distribution centers (VDCS).

Dasci, A. and Verter, V. (2001) considered a production-distribution system design problem (PDSIP). They presented a modeling from work, which was based on the use of continuous functions to represent spatial distributions of cost and customer demand.

Arntzen, B.C. et al. (1995) developed a multi-period, multi-objective, and multi-commodity mixed integer program to solve the global supply chain design problem at Digital Equipment Corporation. This model considered both cost and time in the objective function, thus overall response time of the supply chain could be minimized as an alternative objective.

In fact, the objective function might be a weighted combination of cost and “time-to-market”. The decision variables in the model were location, production, inventory, and shipping quantities. However, multiple capacity levels for each facility were not taken into account in the model. In addition, selecting transportation mode as a variable in the model based on its capacity, lead time, and cost was not considered.

Vidal, C.J. and Goetschalckx, M. (2001) presented a global supply chain design model, considered transfer pricing, transportation costs allocation, inventory costs, and their impact on selection of international transportation modes. The mode choice decision in the model considered trade-off between transportation and pipeline inventory costs.

3. MODEL FORMULATION

The following notation is used in the formulation of the model:

- \( N \) index set of potential assembly plant sites
- \( M \) index set of potential warehouse sites
- \( K \) index set of customers/customer zones
- \( T \) index set of international transportation modes
- \( R \) index set of capacity levels available to potential warehouses
- \( H \) index set of capacity levels available to potential assembly plants
\( C_i^t \) cost of supplying one unit demand to warehouse at site \( i \) from consolidation center by international transportation mode \( t \)

\( \overline{C}_{ij}^t \) cost of supplying one unit demand to assembly plant at site \( j \) from warehouse at site \( i \) by international transportation mode \( t \)

\( \overline{C}_{jk}^t \) cost of supplying one unit demand to customer zone \( k \) from assembly plant at site \( j \) by international transportation mode \( t \)

\( F_{ij}^t \) fixed cost per unit of time for opening and operating warehouse with capacity level \( r \) at site \( i \)

\( G_{jk}^h \) fixed cost per unit of time for opening and operating assembly plant with capacity level \( h \) at site \( j \)

\( L_i^t \) time of transporting a shipment to warehouse at site \( i \) from consolidation center by international transportation mode \( t \)

\( \overline{L}_{ij}^t \) time of transporting a shipment to assembly plant at site \( j \) from warehouse at site \( i \) by international transportation mode \( t \)

\( \overline{L}_{jk}^t \) time of transporting a shipment to customer zone \( k \) from assembly plant at site \( j \) by international transportation mode \( t \)

\( b_i^r \) capacity with level \( r \) for the potential warehouse at site \( i \)

\( e_j^h \) capacity with level \( h \) for the potential assembly plant at site \( j \)

\( a_k \) demand per unit of time of customer zone \( k \)

\( f_i^t \) capacity of transportation mode \( t \) from consolidation center to warehouse at site \( i \)

\( \overline{f}_{ij}^t \) capacity of transportation mode \( t \) from warehouse at site \( i \) to assembly plant at site \( j \)

\( \overline{f}_{jk}^t \) capacity of transportation mode \( t \) from assembly plant at site \( j \) to customer zone \( k \)

The decision variables are:

\( X_{ij}^{rt} \) fraction (regarding \( b_i^r \)) of shipment from consolidation center to warehouse at site \( i \) with capacity level \( r \) by transportation mode \( t \)

\( Y_{ij}^{ht} \) fraction (regarding \( e_j^h \)) of shipment from warehouse at site \( i \) to assembly plant at site \( j \) with capacity level \( h \) by transportation mode \( t \)

\( Z_{jk}^{ht} \) fraction (regarding \( a_k \)) of demand of customer zone \( k \) delivered from assembly plant at site \( j \) transportation mode \( t \)

\[ V_j^h = \begin{cases} 1 & \text{if a assembly plant with capacity level } h \text{ is located at site } j \\ 0 & \text{otherwise} \end{cases} \]

\[ O_i^t = \begin{cases} 1 & \text{if transportation mode } t \text{ is selected for transporting shipment to warehouse at site } i \text{ from CKD center} \\ 0 & \text{otherwise} \end{cases} \]

\[ P_{ij}^t = \begin{cases} 1 & \text{if transportation mode } t \text{ is selected for transporting shipment to assembly plant at site } j \text{ from warehouse at site } i \\ 0 & \text{otherwise} \end{cases} \]

\[ Q_{jk}^t = \begin{cases} 1 & \text{if transportation mode } t \text{ is selected for transporting shipment to customer zone } k \text{ from assembly plant at site } j \\ 0 & \text{otherwise} \end{cases} \]

In terms of the above notation, the problem can be formulated as follows:

\[
Z_{\text{cost}} = \text{Min} \sum_{i \in I} \sum_{r \in R} \sum_{t \in T} \sum_{j \in J} C_{ij}^t X_{ij}^{rt} + \sum_{i \in I} \sum_{r \in R} \sum_{j \in J} \sum_{k \in K} \overline{C}_{ij}^t Y_{ij}^{ht} + \sum_{j \in J} \sum_{h \in H} \sum_{k \in K} G_{jk}^h Z_{jk}^{ht} + \sum_{j \in J} \sum_{t \in T} \sum_{i \in I} \sum_{k \in K} \overline{L}_{ij}^t O_i^t + \sum_{j \in J} \sum_{t \in T} \sum_{i \in I} \sum_{k \in K} \overline{f}_{ij}^t P_{ij}^t + \sum_{k \in K} \sum_{j \in J} \sum_{t \in T} \sum_{i \in I} \sum_{h \in H} \overline{L}_{jk}^t Q_{jk}^t \quad (1)
\]

\[
Z_{\text{time}} = \text{Min} \sum_{i \in I} \sum_{j \in J} \sum_{t \in T} L_i^t O_i^t + \sum_{j \in J} \sum_{h \in H} \sum_{k \in K} \overline{C}_{ij}^t Y_{ij}^{ht} + \sum_{j \in J} \sum_{t \in T} \sum_{i \in I} \sum_{k \in K} \overline{f}_{ij}^t P_{ij}^t + \sum_{k \in K} \sum_{j \in J} \sum_{t \in T} \sum_{i \in I} \sum_{h \in H} \overline{L}_{jk}^t Q_{jk}^t \quad (2)
\]

Subject to:

\[
\sum_{i \in I} \sum_{j \in J} Z_{jk}^t = 1 \quad \forall k \in K, \quad (3)
\]

\[
\sum_{i \in I} \sum_{k \in K} a_k Z_{jk}^t \leq \sum_{h \in H} e_j^h V_j^h \quad \forall j \in N, \quad (4)
\]

\[
\sum_{i \in I} \sum_{k \in K} a_k Z_{jk}^t \leq \sum_{t \in T} \sum_{h \in H} \sum_{j \in J} e_j^h Y_{ij}^{ht} \quad \forall j \in N, \quad (5)
\]
The model minimizes total cost and lead times of a global supply chain. First objective function, \( Z_{\text{cost}} \), consists of: the costs of shipments from the consolidation center to the warehouses, the costs of shipments from the warehouses to the assembly plants, the costs to serve the demands of customers from the assembly plants, and finally the costs associated with opening and operating the warehouses and the plants. Second objective function, \( Z_{\text{time}} \), is made of: time of transporting shipments from the consolidation center to the warehouses, the time of transporting shipments from the warehouses to the assembly plants, the time of transporting shipments from the plants to customers, and finally the time of assembling products in the assembly plants.

Constraint set (3) ensure that the demands of all customers are satisfied by open assembly plants. Constraint sets (4) and (5) guarantee that the total customer demands satisfied by an assembly plant do not exceed both the capacity of the plant and the total shipments to the plant from all open warehouses by all transportation modes, respectively. Constraint sets (6) and (7) ensure that the total demands of assembly plants satisfied by an open warehouse do not exceed both the capacity of the warehouse and the total shipment to the warehouse from the consolidation center by all transportation modes, respectively. Constraint sets (8) and (9) state that an assembly plant and warehouse, respectively, can be assigned at most one capacity level. Constraints in set (10) stipulate that the flow of shipments to a warehouse at a specific site can only be positive if a warehouse is located at that site. Similarly, Constraints in set (11) stipulate that the flows of shipment from all warehouses to an assembly plant at a specific site can only be positive if a plant is located at that site. Constraint sets (12), (13), and (14) guarantee that flow of shipment by particular transportation mode to a warehouse, assembly plant and customer zone, respectively, can only be positive if that transportation mode is selected. We assume that at most one transportation mode is allowed between two nodes (consolidation center, warehouses, assembly plants, and customers) in the global supply chain. Constraint sets (15), (16), and (17) consider this assumption. Finally, constraints in sets (18), (19), and (20) enforce that non-negativity restrictions on corresponding decision variables and constraints in sets (21) - (25) enforce the integrality restriction on binary variables.

4. SOLUTION PROCEDURE

The model proposed in the previous section is a mixed integer multi-objective linear programming problem. Various algorithms exist for providing optimum solution of the problem; deterministic methods such as weighting method, weighted \( L_p \)-metrics method, goal programming and stochastic search techniques such as evolutionary algorithms. In this research, weighted \( L_p \)-metrics method (WLp) is used to solve the problem. In this method, references points are calculated by minimizing model with each single objective function. Then, the weighted distance between these references points and the feasible objective region is minimized. In this way,
the multiple objective functions are transformed into a single objective function (Miettinen, K., 1998). The weighted $L_p$-metrics method belongs to posterior methods category. It means, after Pareto optimal set has been generated, it is presented to the decision maker who selects the most preferred among the alternatives. From definition of Pareto optimality, $X^*$ (a feasible decision variable vector) belongs to Pareto optimal set, if there exists no feasible vector $X$ which would decrease one objective function without causing a simultaneous increase in other objective functions (Coello Coello, C.A. et al., 2007).

Let $Z^*_\text{cost}$ and $Z^*_\text{time}$ be objective values for cost and time objective functions when only one objective exists in the model. The relevant weighted $L_p$-metrics are:

$$WLP = \left[ \lambda \left( \frac{Z^*_\text{cost} - Z^*_\text{cost}}{Z^*_\text{cost}} \right)^p + (1 - \lambda) \left( \frac{Z^*_\text{time} - Z^*_\text{time}}{Z^*_\text{time}} \right)^p \right]^{1/p}$$  \hspace{1cm} (26)

In general, relative deviations of form $(Z^*_\text{cost} - Z^*_\text{cost})$ and $(Z^*_\text{time} - Z^*_\text{time})$ are preferred over absolute deviations, because they have a substantive meaning in any context.

The value of $P$ indicates the type of distance: for $p = 1$, all deviations from $Z^*_\text{cost}$ and $Z^*_\text{time}$ are taken into account in direct proportion to their magnitudes, which corresponds to group utility. For $2 \leq p < \infty$, the larger deviations carry greater weight in $WLP$ (e.g. Coello Coello et al., 2007). In this research, all deviations are considered in direct proportion and $p$ is equal to 1. Since the weighted $L_1$-metric is linear combination of two objective functions, whatever $\lambda$ increases, importance of cost objective function will increase more than time objective function. Using weighted $L_p$-metrics method, linear programming model can be formulated as follows:

$$WL_1 = \lambda \left( \frac{Z^*_\text{cost} - Z^*_\text{cost}}{Z^*_\text{cost}} \right) + (1 - \lambda) \left( \frac{Z^*_\text{time} - Z^*_\text{time}}{Z^*_\text{time}} \right)$$  \hspace{1cm} (27)

Subject to (3) to (25)

The model is tested with actual data obtained from an automotive company that considered reconfiguring its global supply chain with respect to time to market and cost concurrently. The company is one of the largest car manufacturers in the Middle East. The firm provided customers demands, capacities of warehouses and plants over 1 year. The supply chain consists of 1 consolidation center, 5 potential warehouses with 3 capacity levels, 7 potential plants with 4 capacity levels and 7 customer zones with identified demands.

The more facility capacity level increases, the more fixed cost for opening and operation will increase. Three different transportation modes, rail, highway, and water, are considered between facilities. Cost of highway transportation is more than rail transportation and cost of rail transportation is more than water transportation. In opposition, water transportation time is more than rail transportation, and time of rail transportation is more than highway transportation.

The resultant single objective mixed integer linear programming model is displayed in Table 1. In this table cost and time objective values are presented with respect to different $\lambda$ values.

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>$Z^*_\text{cost}$ ($\text{$}$)</th>
<th>$Z^*_\text{time}$ (day)</th>
<th>CPU time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>232190</td>
<td>7.4</td>
<td>00:48</td>
</tr>
<tr>
<td>0.1</td>
<td>177800</td>
<td>7.4</td>
<td>02:17</td>
</tr>
<tr>
<td>0.2</td>
<td>171775</td>
<td>7.5</td>
<td>01:05</td>
</tr>
<tr>
<td>0.3</td>
<td>162575</td>
<td>8</td>
<td>07:36</td>
</tr>
<tr>
<td>0.4</td>
<td>112150</td>
<td>11.1</td>
<td>11:01</td>
</tr>
<tr>
<td>0.5</td>
<td>88050</td>
<td>13.3</td>
<td>8:14</td>
</tr>
<tr>
<td>0.6</td>
<td>84250</td>
<td>13.8</td>
<td>4:06</td>
</tr>
<tr>
<td>0.7</td>
<td>68700</td>
<td>17</td>
<td>4:25</td>
</tr>
<tr>
<td>0.8</td>
<td>68700</td>
<td>17</td>
<td>4:08</td>
</tr>
<tr>
<td>0.9</td>
<td>66900</td>
<td>18</td>
<td>12:02</td>
</tr>
<tr>
<td>0.95</td>
<td>59700</td>
<td>30.5</td>
<td>29:51</td>
</tr>
<tr>
<td>0.975</td>
<td>58500</td>
<td>36.5</td>
<td>32:28</td>
</tr>
<tr>
<td>1</td>
<td>57025</td>
<td>118.1</td>
<td>00:20</td>
</tr>
</tbody>
</table>

Figure 2 The Pareto front or trade off surface between cost and time objective functions.
One of the main advantages of WLp, is ability to generate nondominated solution. It can be proved that solving problem (27) for each $\lambda$ value, generates a nondominated solution. In Figure 2, the Pareto front or trade off surface between cost and time objective functions is delineated by a curved line. If $\lambda = 1$, problem solution is equivalent with $Z^*_\text{time}$. As expected, increasing $\lambda$ value causes decreasing cost objective function and increasing time objective function. Therefore, decision maker can select solutions via choice of acceptable objective performance represented by Pareto frontier. Identifying a set of Pareto optimal solutions is thus key for a DM’s selection of a compromise solution satisfying time and cost objective functions as best possible.

Another analysis that one can do in the problem is usage percentage of each transportation mode for different value of $\lambda$. As mentioned previously, with increasing the $\lambda$ value, we except the model to increase cost importance, so that the transportation modes that have lower cost are used more. On the other hand, with decreasing the $\lambda$ value, the time importance increases, and in designing the global supply chain, the transportation modes with lower time are used more. It is obvious that these transportation modes may have more costs. In Figure 3, percentage of usage of each transportation mode is illustrated. When $\lambda$ increases, the less expensive transportation modes are used more (such as water transportation mode). Oppositely, when $\lambda$ decreases, the short lead-time transportsations modes are used more (such as highway transportation mode).

**Figure 3** Percent of usage of each transportation mode in optimal solution.

5. CONCLUSION

In this paper, we studied the problem of designing a global supply chain that involves determining simultaneously the best sites of both warehouses and assembly plants, and the best strategy for transporting products in the network. Unlike the most of past researchs, our study considers different transportation modes as decision variables. We developed a multi-objective linear programming model that encompasses cost and lead time objective function. We showed that with using WLp method, one can generate numerous nondominated solutions (Pareto frontier), and this solution can provide DM with more consciousness of design alternatives. Therefore, he/she can select most favorite structure from cost and time point of view. At the end, $L_p$-metrics method, is used to solve the problem.

REFERENCES


