Indian Journal of Science and Technology, Vol 8(35), DOI: 10.17485/ijst/2015/v8i35/68775, December 2015
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

A Multi-Objective Model in Cross Docks Location Problems Considering Data Envelopment Analysis

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Abstract

Background/Objectives: This paper deals with a cross docking distribution strategy where the system consists of O suppliers, J potential location for cross docks and K retailers. In addition all vehicles are equal. **Methods/Statistical Analysis**: To find an effective policy for this system, a mathematical multi-objective model with aim to minimizing the travelled distance costs between origins and facilities and also between facilities and destinations, minimizing the fixed cost of constructing a cross-dock and maximizing the benefits of being close to the facilities is formulated. **Findings:** The previous models for problem at hand don't consider cross docks location technical efficiency so it may led to selecting inappropriate sites. To deal with this dilemma, data envelopment analysis approach added to model as a new objective function and several constraints makes the model more applicable to real-world systems. The mathematical model of this problem belongs to nonlinear mixed integer-programming and hence a parameter-tuned simulated annealing is proposed to solve it efficiently. The results of solving numerical examples show the applicability of the proposed methodology clearly. **Application/Improvements**: Because of considering technical efficiency for each dock, mathematical model is closer and more applicable to real-world environments than the other existing ones.

Keywords: Cross Docking, DEA, Distribution, Location

1. Introduction

Cross docking is an innovative logistics strategy in supply chain widely used by almost every company to distribute their product efficiently. As compared to traditional warehousing in cross docking the goods are received and loaded immediately on outgoing trucks, often less than 24H[1].

After freight unloaded from incoming tracks, they regrouped and stored temporary on the top of each other or on the dock ground for just few hours. Then loaded and redistribute based on their destinations. However every product can use cross docking as a transshipment facility, time sensitive products with high and anticipated demand are best candidates. Because of some reasons such as reduction in handling and holding costs and elimination order picking which lead to reduction in response time and finally promotion in end customer services, many companies tend to using cross docking instead of warehousing. In order to effective cross docking implementation managers must pay enough attention to main factors. For example the supplier must have reliable activity with short lead time because there is not lateral stock between supply and demand nodes and also information must be accessible through the whole of supply chain[2].

This research involve finding the best location of one or more cross docks from several potential sites (location) and then determine how amount of delivered goods from origin via cross docking to demand points (allocation).

In this section we focus on some research related to location/allocation of cross docking. Sung and Song[3] considered a service network design problem concerned with integration of positioning C-D centers and allocating vehicles under capacity and service time restriction. So they presented a path-passed model in order to total cost minimization including fixed and transportation cost and solve it with a meta-heuristic method entitled tuba search.

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Computational experiments show that the solution was effective and reached better lower bound.

Jayaraman and Ross[4] study a multi echelon design system in which goods belongs to multiple product families. In order to select the best set of distribution centers and cross docks the strategic model (planning stage) was presented. Another stage (executing) deals with deciding the required quantity of product families that must be transported via distribution centres and cross docks.

Ross and Jayaraman[5] developed two new heuristic based on simulated annealing for the location of cross docking and distribution centers in which products belongs to multiple families. Their results show that integrating simulated annealing with tabu search provides better solution. Sung and Yang[6] presented a branch and price algorithm in order to optimally locate cross docking centers and allocate vehicle with minimum cost and restricted delivery time.

In order to minimize fixed and variable cost and maximizes the plant flexibility and volume flexibility, Bachlaus et al.[7] presented a multi-objective optimization model an integrated for a five-echelon agile supply chain network including suppliers, plants, cross docks, distribution centers and customers. Underlying model has high complexity therefore they implement a novel algorithm named hybrid particle swarm optimization as a solving method.

Musa et al.[8] presented an integer programming model to minimize the transportation cost in a cross docking network. In their study frights can transport directly to end customers or via cross docking center. Then they solve it with ant colony optimization method.

Experimental finding shows that their approach decrease shipping cost. In order to evaluating the performance of cross docking system in a supply chain network, Hagan et al.[9] developed a Data Envelopment Analysis (DEA) approach. They presented an iterative two-stage method: first ranking cross docks based on discretionary variables via DEA and second adjusting them based on non-discretionary variables. This approach presented a set of adjusted Decision Making Units (DMU) ranking with aim to the best technical efficiency.

Gumuş and Bookbinder[10] considered three multi echelon networks including cross docking center with aim to minimize total cost.

Kordrostami et al.[11] developed a new model in interval dynamic network DEA for production systems and showed the appliance of their approach in Iranian banks. Hajihosseini et al.[12] focused on a work that proposes less computation. In addition they developed a new approach to measuring congestion in DEA with common weights.

In this paper, a supply chain system is considered as a networkincluding suppliers (plants), cross docks and destinations.More specifically, the problem that is considered consists of across docking distribution strategy where the system consists of O suppliers, K retailers and J potential location for cross docks.

In addition all vehicles are equal. For example all vehicles to transport fright are trucks with the same capacity. To find an effective policy for this system, with aim to minimizing the travelled distance costs between origins and facilities and also between facilities and destinations, minimizing the fixed cost of constructing a cross-dock, maximizing the benefits of being close to the facilities, maximizing the technical efficiency of docks via data envelopment analysis a mathematical multi-objective model is formulated. This research is an extension of Makui et al.[13] model by considering data envelopment analysis approach. The mathematical model of this problem belongs to nonlinear mixed integer-programming and hence a parameter-tuned simulated annealing is proposed to solve it efficiently. The results of solving numerical examples show the applicability of the proposed methodology clearly. Data Envelopment Analysis (DEA) is a non-parametric method determines the relative efficiencies and measured by the ratio of the sum of weighted outputs to the sum of weighted inputs[14].

$$DEA\ Effieicncy = \frac{Sum\,of\ wieghted\,outputs}{Sum\,of\ wieghted\,inputs} \qquad (1)$$

Nevertheless, DEA has been widely applied in different problems such as manufacturing system, human development and system performance but using DEA with location problem is still rare.

By integration of DEA efficiency measure and location modelling objectives, a promising rich approach to multi-objective location problems is provided[15]. The previous models for problem at hand don't consider cross docks location technical efficiency so it may led to selecting inappropriate sites. To deal with this dilemma, data envelopment analysis approach added to model as a new objective function and several constraints makes the model more applicable to real-world systems. In addition, the solution method that is based on a parameter tuned simulated annealing algorithm works quite well.

The remainder of the paper is organized as follows. Section 2 is presented the definition and mathematical formulation of the problem. Comprehensive explanation of the algorithm proposed to solve the model is discussed in Section 3. In Section 4, parameter adjustment and numerical tests are reported. Finally, some conclusions are given and future research directions are proposed in Section 5.

2. Mathematical Model

Consider a supply chain network for a non-repairable item where the system consists of O suppliers, K retailers and J potential location for cross docks. In addition transferring incoming loads from stack doors were implemented directly to outgoing vehicles (outbound trucks) doors within a few hours. In these systems a product received from an outside suppliers or plants for several retailers to satisfy the demand of retailers that is ordered based on their ordering policy. Figure 1 shows the schematic of a cross docking system.

The problem at hand is formulated with minimizing the travelled distance costs between suppliers and facilities and also between facilities and retailers, minimizing the fixed cost of constructing a cross-dock, maximizing the benefits of being close to the facilities, maximizing the technical efficiency of docks subject to location related constraints and DEA related constraints.

The following notations, parameters and variables are used for mathematical model of the problem:

K The set of retailers (destinations) nodes $K = 1, \ldots, k$

J The set of potential crossdocks. DMUs $j = 1, \ldots, r, \ldots, J$

O The set of existing suppliers (origins) $O = 1, \ldots, o$

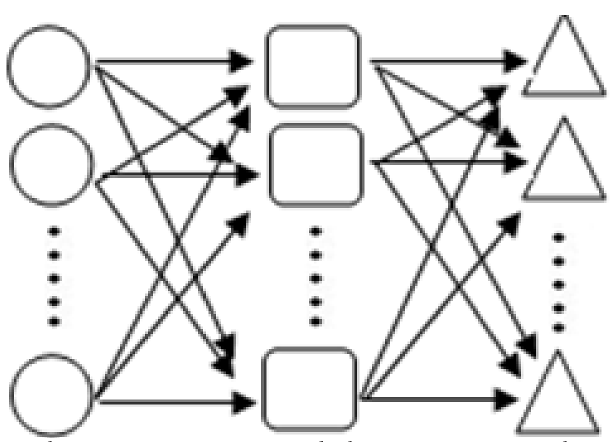

Figure 1. Cross docking in supply chain network.

d_{ok} The demand of the retailer k for the products of the supplier o

a_{oj} The capacity of cross-dock j for receiving product o (kg)

b_j The fixed cost for opening/operating cross dock j ($)

m_{oj} The distance between origin o to cross-dock j (km)

m'_{jk} The distance between cross-dock j to destination k (km)

c_{oj} The cost of travelling a unit of distance from origin o to cross dock j ($)

c'_{jk} The cost of travelling a unit of distance between cross dock j and destination k ($)

e The truck capacity (kg)

s_o The weight of per unit of product o (kg)

p_o The production capacity of the supplier o (kg)

h_j Indicates the degree of being close to the facilities

I Inputs used at DMU $i = 1, \ldots, I$

N Outputs produced at DMU $n = 1, \ldots, N$

d'_r The level of inefficiency of DMU r

o'_{nj} Amount of the nth output for the jth DMU

I_{ij} Amount of the ith input for the jth DMU

u_{nr} The weight assigned to the nth output for DMU r

v_{nr} The weight assigned to the nth input for DMU r

$$y_j \begin{cases} 1 & \text{If the node j is chosen as a cross-dock} \\ 0 & \text{Otherwise} \end{cases}$$

$$z_{jk} \begin{cases} 1 & \text{If the cross-dock j is assigned to the retailer k} \\ 0 & \text{Otherwise} \end{cases}$$

$$q_{oj} \begin{cases} 1 & \text{If the cross-dock j is assigned to the supplier o} \\ 0 & \text{Otherwise} \end{cases}$$

x_{ojk} Amounts of the delivered products from supplier o via cross-dock j to the demand point k.

Thus, the mathematical formulation of the problem becomes:

$$Obj1: Min \sum_{o=1}^{O}\sum_{j=1}^{J}\sum_{k=1}^{K} c_{oj}x_{ojk}m_{oj}\frac{e}{s_o} + \sum_{o=1}^{O}\sum_{j=1}^{J}\sum_{k=1}^{K} c'_{jk}x_{ojk}m'_{jk}\frac{e}{s_o} \tag{2}$$

$$Obj2: Min \sum_{j=1}^{J} b_j y_j \tag{3}$$

$$Obj3: Max \sum_{j=1}^{J} h_j y_j \tag{4}$$

$$Obj4: Max \sum_{k=1}^{K}\sum_{j=1}^{J}(1-d'_{jk})z_{jk} \tag{5}$$

St:

$$\sum_{j=1}^{J} z_{jk} \geq 1 \forall k \in K \tag{6}$$

$$\sum_{j=1}^{J} q_{oj} \geq 1 \forall o \in O \tag{7}$$

$$z_{jk} \leq y_j \forall k \in K \forall j \in J \tag{8}$$

$$q_{oj} \leq y_j \forall j \in J \forall o \in O \tag{9}$$

$$\sum_{j=1}^{J}\sum_{k=1}^{K} x_{ojk} q_{oj} \leq p_o \tag{10}$$

$$\sum_{j=1}^{J} x_{ojk} q_{oj} z_{jk} = d_{ok} \ \forall k \in K \ \forall o \in O \tag{11}$$

$$\sum_{k=1}^{K} x_{ojk} \leq a_{oj} \ \forall j \in J \ \forall o \in O \tag{12}$$

$$\sum_{i=1}^{I} v_{jki} I_{jki} = z_{jk} \ \forall k \in K \ \forall j \in J \tag{13}$$

$$\sum_{n=1}^{N} u_{jkn} o'_{njk} + d'_{jk} = z_{jk} \forall k \in K \ \forall j \in J \tag{14}$$

$$\sum_{n=1}^{N} u_{jkn} o'_{nrs} \leq \sum_{i=1}^{I} v_j I_{irs} \tag{15}$$

$$u_{jkn} \geq \varepsilon z_{jk} \forall j \in J \ \forall k \in K \ \forall n \in N \tag{16}$$

$$v_{jkn} \geq \varepsilon z_{jk} \forall j \in J \ \forall k \in K \ \forall i \in I \tag{17}$$

$$u_{jkn} o'_{njk} \leq z_{jk} \ \forall j \in J \ \forall k \in K \ \forall n \in N \tag{18}$$

$$x_{ojk} \geq z_{jk} \ \forall j \in J \ \forall k \in K \ \forall o \in O \tag{19}$$

$$x_{ojk}, u_{jkn}, u_{jki} \geq 0 \tag{20}$$

$$z_{jk}, y_j, q_{oj} = 0,1 \tag{21}$$

Equation (2) gives the first objective function of the model. It refers to the total travelled distance costs between suppliers and facilities and also between facilities and retailers. Equation (3) gives the second objective function of the model and indicates the fixed cost of constructing a cross-dock. The benefits of being close to facilities presented in third equation and final objective shows sum of technical efficiency of docks. Constraints 6 and 7 assure that each cross dock is connected to at least one demand point and each cross dock is assigned to at least one supplier, respectively. Constraint 8 assures that just chosen cross dock can assign to the demand point. In the other word, one or more cross docks must service to a demand point. Constraint 9 assures that only chosen cross dock can assign to the supplier. Constraint 10 guarantees that total delivered products from supplier o via cross-dock j to the demand point k is not greater than the production capacity of the supplier. Constraint 11 represents that demand of the retailer (destination) k is equal to delivered products from supplier o via cross-dock j to the demand point k. Constraint 12 shows that the delivered products throughout the system is not greater than the capacity of the cross dock. Constraints 13-18 are related to data envelopment analysis. Constraint 13 shows that the sum of DMU i's weighted input is equal to one when the cross-dock j is assigned to the demand point k. Constraint 14 shows similar concept about outputs. Constraint 15 represents that the sum of weighted outputs is not greater than the sum of weighted inputs. Constraint 16 and 17 show that if the cross-dock j is assigned to the demand point k, weighted outputs and weighted inputs are not less than small infinitesimal number (ε) respectively. Constraint 18 shows that the sum of DMU i's weighted output is not greater than one when the cross-dock j is assigned to the demand point k. Constraint 19 guarantees that at least one unit to be transfer from cross duck j to demand point k when cross dock j connected to demand point k. Finally, constraint 20 and 21 represent the ranges of the decision variables.

In the next section, a meta-heuristic algorithm is presented for the location/DEA model of the problem at hand.

3. The Proposed SA Method

The model introduced and formulated in the previous section belongs to NP-Hard class and have high complexity, therefore solving it with the exact methods quite impossible. In such cases meta-heuristic algorithms can be used effectively. Although expecting an optimal solution via these algorithms in many problems improbable but a near optimal answer with a good trade off between speed and quality is quite achievable. In order to solve the mathematical model at hand, an optimization technique based on physical annealing process (simulated annealing algorithm) was implemented.

Fundamental idea of SA is from Kirkpatrick et al.[16] that is the first one uses metropolis algorithm to approximate numerical simulation and developed a natural tool for bringing the techniques of statistical mechanics to optimization.

Simulated annealing improves step by step via generating and evaluating an initial set of random solution[17]. Then the neighbourhoods of the problem that are produced first, evaluate again. If the neighbours have better quality (capable to decrease objective function) they are selected to copy in the next generation. SA allows inadequate solution to copy in the next generation based on a defined probability function. Almost every solution is accepted in the higher temperature, irrespective of their energy function. SA considers an initial temperature and in every temperature generating of new solution is continues. If the number of solution larger than a predefined limit (define by user) the temperature reduced. After lowering the temperature several times, the algorithm can terminate. The set of solution become better and better from temperature to temperature until satisfying solution is obtained.

Generally, the proposed SA implement according to the following algorithm:

Algorithm 1

The general steps involved in the proposed SA.

(i) Input initial requirement including starting and final temperature, cooling rate and iterations at each temperature.
(ii) Create initial generation of solution randomly.
(iii) Evaluate all members of the current generation via energy function.
(iv) Repeat until final temperature is obtained.
- producing neighbour.
- evaluate each neighbour.
- if the solution accepted preserve it otherwise evaluates another neighbours.
- reduced temperature.

(v) Out put.

To evaluate each of solution structure defining energy function is necessary. In most of SA problems, objective function is considered as an energy function but as explained before, our model has sixteen constraints so in order to make solution permissible and a penalty function is defined as a positive and known sum of square violation of each constraint. At the end penalty function added with objectives function.

Energy Function = Penalty Function+ [obj1+obj2-obj3-obj4]

To produce new neighbours two elements of solution structure replaces with each other randomly (RIS method). In order to search more to better quality solution, final temperature in considers zero. In addition for decreasing the temperature the following formulation was used:

$$temperature_{now+1} = \alpha \times Temperature_{now}$$
$$\text{Where } \alpha \in (0,1) \tag{22}$$

In the next section, a numerical example is provided to demonstrate the application of the proposed approach in real-world systems.

4. Computational Result

Consider a cross docking system of this research that consist of two suppliers, four potential location for cross docks and two retailers. We want to select the location of cross dock among 4 candidate, therefore nine criterion consist of adequate equipment, competent management, quality of inbound and outbound tracks, storage area, personnel skill, information technology, lateness in shipment, bad climate and damage products in docks or in delivery was introduced. Two of these criterion have negative concept (bad climate and damaged products) so we consider them as inputs and others as outputs. Table 1 and Table 2 show the general and DEA data for solving the model respectively.

Before solving the main model of problem via simulated annealing, calculating the technical efficiency is required. So the first classical model of DEA introduced first Charnes, Cooper and Rhodes[4] named CCR was used in this stage. Table 3 shows the different value of DEA variables.

In order to determine the best value for SA parameters (the starting temperature T_0, the final temperature T_f, the number of iterations at each temperature I and cooling rate α) that result in a better solution, a taguchi procedure is implemented. In this approach, the proposed SA runs 9 times with different values of mentioned parameters. Then the energy function is recorded in each run. Table 4 shows the results of the first 9 runs. In addition Figure 2 shows the main effect plot for mean and SN ratios.

Table 1. General data

Data	o=1 j=1 k=1	o=1 j=2 k=1	o=1 j=3 k=1	o=1 j=4 k=1	o=1 j=1 k=2	o=1 j =2 k=2	o=1 j=3 k=2	o=1 j=4 k=2	o=2 j=1 k=1	o=2 j=2 k=1	o=2 j=3 k=1	o=2 j=4 k=1	o=2 j=1 k=2	o=2 j=2 k=2	o=2 j=3 k=2	o=2 j=4 k=2
b_j	120000	300000	450000	224500												
a_{aj}	64	26	40	18									39	45	24	19
d_{ok}	23.27				6.1				16.14				6.14			
m_{oj}	23	35	52	34									35	75	56	63
m'_{jk}	53	35	19	20									51	24	45	44
c_{oj}	9.80	9.87	5.67	4.56									9.51	4.5	7.54	3.45
c_{jk}	6.78	5.62	4.57	2.34									9.45	3.4	7.64	4.87
e	10000															
s_o	110								150							
p_o	1234								4321							
h_j	1.54	1.65	1.98	1.21												

Table 2. DEA data

Cross docks	retailer	Bad Climate	Damaged Products	Lateness In Shipment	Quality Of Tracks	Management	Equipment	Information Technology	Personnel Skill	Storage Area
C-D1	1	0.27	0.11	0.31	0.65	0.61	0.52	0.78	0.84	0.89
C-D1	2	0.61	0.65	0.89	0.13	0.23	0.32	0.14	0.40	0.49
C-D2	1	0.67	0.65	0.49	0.43	0.33	0.42	0.54	0.20	0.29
C-D2	2	0.59	0.57	0.71	0.54	0.26	0.34	0.11	0.32	0.24
C-D3	1	0.61	0.52	0.69	0.24	0.59	0.74	0.46	0.29	0.58
C-D3	2	0.67	0.65	0.49	0.53	0.39	0.47	0.44	0.20	0.21
C-D4	1	0.32	0.51	0.49	0.14	0.79	0.44	0.66	0.35	0.52
C-D4	2	0.39	0.27	0.21	0.74	0.86	0.74	0.61	0.62	0.53

Table 3. DEA results

Cross docks	retailers	DEA score	d'_r
C-D1	1	1	0
C-D1	2	0.27	0.73
C-D2	1	0.40	0.6
C-D2	2	0.38	0.62
C-D3	1	0.63	0.37
C-D3	2	0.38	0.62
C-D4	1	1	0
C-D4	2	1	0

Table 4. Numerical results of 9 runs

Energy Function	T_o	I	T_f	α	Test Problem
1	100.00	100.00	0.00	0.99	6719038.16
2	100.00	50.00	5.00	0.50	7113034.11
3	100.00	20.00	10.00	0.10	17456724.54
4	60.00	100.00	5.00	0.10	8163862.12
5	60.00	50.00	10.00	0.99	8796250.51
6	60.00	20.00	0.00	0.50	8736122.73
7	20.00	100.00	10.00	0.50	7765287.55
8	20.00	50.00	0.00	0.10	9224567.72
9	20.00	20.00	5.00	0.99	9123743.65

With respect to above figures we can conclude the best starting and final temperatures are 60.00, 5, respectively. Cooling rate 0.5 and 100 iteration in each temperature. Employing the proposed SA with the obtained values of the parameters, the algorithm converges to the following solution with energy function of 6524532.01. As we can see from the result just cross dock no 1, 3 selected among all of candidates. Figure 3 shows this typical solution.

$$x_{111} = 7.13, x_{131} = 16.14, x_{231} = 91.19, x_{132} = 6.14, x_{232} = 97.58,$$
$$z_{11} = z_{31} = z_{32} = 1, y_1 = y_3 = 1, q_{11} = q_{13} = q_{23} = 1$$

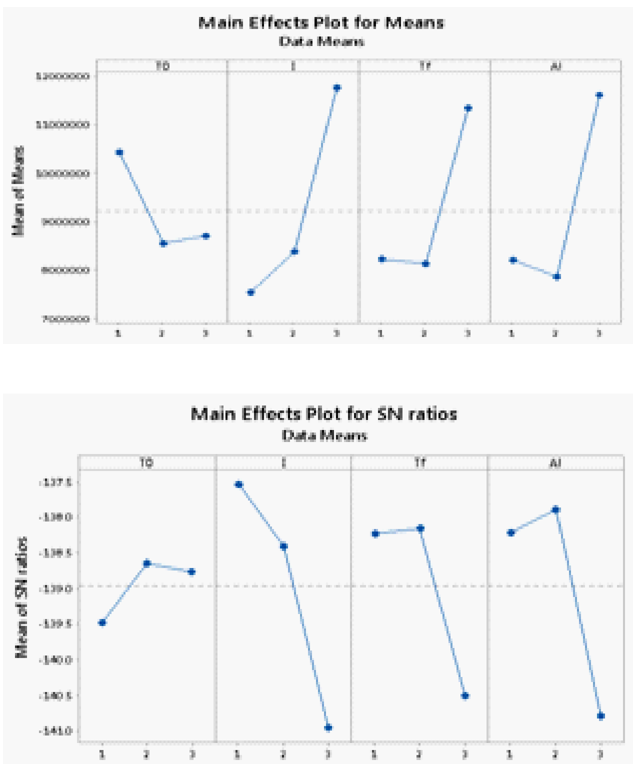

Figure 2. Mean and SNR of algorithm.

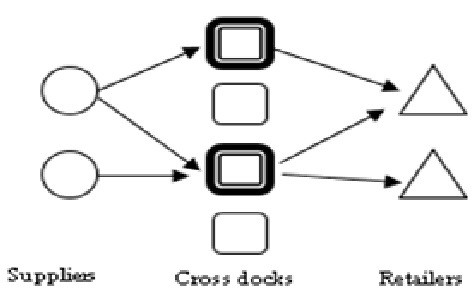

Figure 3. A typical solution.

5. Conclusion

In this research, a new model for a cross docking system in supply chain networks was developed to find the best location/DEA parameters that minimize the travelled distance costs between origins and facilities and also between facilities and destinations, minimize the fixed cost of constructing a cross-dock, maximize benefits of being close to the facilities and maximizing the technical efficiency of docks via data envelopment analysis subject to location and DEA constraints. Because of considering technical efficiency for each dock, model is closer and more applicable to real-world environments than the other existing ones.

Future research may extend the model by considering different objectives, constraints or integrating with uncertainty. In addition implementing different solving methods are obviously possible and might lead to more efficient solutions.

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