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An improved response time-constrained optimization model and solving algorithm for supply chain network design considering transport mode impacts

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ABSTRACT

Supply chain network design has a great and long impact on both the structure and value of the supply chain network. More and more firms are willing to optimally design their supply chain network so as to reduce their operation cost and improve their competence. In this paper, a referenced mixed integer non-linear programing optimization model considering market response time is solved using CPlex software instead of Lingo11 software and it seems that an optimal solution can be got readily. Based on this model, an improved mixed integer nonlinear programming (MINLP) model considering transport mode impacts which will affect response time is developed. The model's objective is to maximize the total profit and decision variables include transportation amounts between facilities, transport mode selection etc. Hereafter, a hybrid intelligent optimization method which takes full advantage of CPlex software and genetic algorithm is designed to solve the model. Finally, an illustrative supply chain network model is solved using the hybrid algorithm put forward. The results demonstrate the model's effectiveness and the algorithm's feasibility compared to the original model and other algorithms.

KEYWORDS

Response time-constrained; Transport mode; Mixed integer nonlinear programming; Hybrid intelligent algorithm; Supply chain network.

INTRODUCTION

In today's globally competitive trade world, merger and acquisition among corporations are emerging in an endless stream. As a result, supply chain network including these corporations is becoming more complicated, and sets an even higher demand on its design and configuration. Generally speaking, a supply chain network is a set of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer[1]. It will be very difficult for corporations' long-term survival without highly optimized and strategic and tactical supply chain model. Savings in the 5–10% range, which can be achieved by using strategic and tactical supply chain network models, will dramatically affect the profitability of the corporation[2].

The supply chain network design problem can be defined as follows: given a set of potential suppliers, potential manufacturing facilities, and distribution centers with multiple possible configurations, and customers with deterministic demands, determine the configuration of the production–distribution system and the transfer prices between various subsidiaries of the corporation such that seasonal customer demands and service requirements are met and the profit of the corporation is maximized[3].

There are many studies on the application of mathematical programming models and algorithms in the field of supply network design (Dhaenens-Flipo, 2000; Amiri, 2006; NgaThanh et al., 2008; Longinidis & Georgiadis, 2011; Mahdi Bashiri et al., 2013)[4-8]. In general, these optimization models mentioned above are formulated as mixed integer programs and solved by commercial software package such as Cplex, LINGO etc or by decomposition techniques and heuristic methods. However, the impact of different transportation modes on supply chain network design and configuration has not been studied deeply (E Olivares-Benitez et al., 2010). Not only does cost-time need a tradeoff produced by transportation choices, but some environmental aspects which is sustainable supply chain network's focus should be concerned since transport sector is the significant source of CO2 emissions (Wilhelm et al., 2005; Cordeau, J.-F. 2006; Lu et.al, 2007; Anna Nagurney, 2010; Sadjady, H., 2011; Yu-Chung Tsao, 2012; Xiaopeng Li, 2013)[9-15].

In this paper, taking into transport mode consideration, we try to develop an improved optimization model and its solving algorithm for supply chain network design of Cao's model which is a multi-echelon model for production-distribution networks[16]. The rest of paper is organized as follows. In section 2, the original response time-constrained MINLP model is introduced and solved using CPlex in Excel, then we present an improved MINLP model considering transport mode which will have impacts on response time and develop a hybrid intelligent optimization method based on CPlex software and genetic algorithm to solve the model. To illustrate application of the improved model, a hypothetical numerical example is cited and compared for the model's effectiveness and algorithm's feasibility in section 3. Finally conclusions are summarized and further researches are drawn in section 4.

RESPONSE TIME-CONSTRAINED OPTIMIZATION MODEL AND ALGORITHM

Original Response Time-constrained MINLP Model

A mixed integer nonlinear programming model considering market response time constraint is proposed in paper[16], but the model optimal solution of the case using Lingo11 software is not really got. Although the model is nonlinear, it can be transformed into MIP model so we can use CPlex to solve the case. And the model optimal solution is superior to the solution using Lingo11. It can be compared as TABLE 1. depicts.

TABLE 1 : Optimal solution comparison

Item	Lingo11	Cplex
Profit	30490000	30505000
Supplier1->Factory2	350	350
Supplier1->Factory3	100	100
Supplier2->Factory2	150	150
Supplier3->Factory3	300	300
Factory2->DC2	500	500
Factory3->DC1	0	250
Factory3->DC2	400	150
DC1->Market2	0	250
DC2->Market1	450	450
DC2->Market2	50	200
DC3->Market2	400	0

An Improved MINLP Model

Considering transport mode such as truck, railway, airline etc. affecting market response time, an improved MIP model based on the existed model in the model mentioned above is proposed.

Assumptions

- The various assumptions involved in this paper are described as below.
- Products only can be transferred from each supplier to all plants, from each plant to all distributors and from each distributor to all customer zones.
- Each supplier has a restriction on the available raw materials.
- Customer demand is deterministic and is necessary to satisfy all customer demands.
- Different customer zones' price is predictable, and the function concerning response time, sales income, total cost can be fitted according to data analysis.
- Unit cost of different transport mode affecting response time can be got.

Model notation and formulation

Notation: TABLE 2 shows the definition of sets, parameters and variables which are necessary to define the model for the problem under consideration.

Formulation: The mathematical formulation is as follow:

$$\begin{aligned} \text{Max} \quad V = & \sum_{j=1} F(T_j) P_j \sum_i \sum_e z^i_{e,j} - \\ & [\ \sum_n F_n u_n + \sum_e H_e v_e \\ & + \sum_l \sum_n \sum_i C^i_{l,n} x^i_{l,n} + \sum_n \sum_e \sum_i C^i_{n,e} y^i_{l,n} \\ & + \sum_e \sum_j \sum_i C^i_{e,j} z^i_{e,j} + C_{total} G(T_1, T_2, \cdots, T_j)\ ] \end{aligned} \tag{1}$$

$$\sum_{n}\sum_{i} x^{i}_{l,n} \le S_l, \forall l \in L \quad (2)$$

$$\sum_{e}\sum_{i} y^{i}_{n,e} \le K_n u_n, \forall n \in N \quad (3)$$

$$\sum_{j}\sum_{i} z^{i}_{e,j} \le W_e v_e, \forall e \in DC \quad (4)$$

Subjected to: $\sum_{e}\sum_{i} z^{i}_{e,j} \ge D_j, \forall j \in CM \quad (5)$

$$\sum_{l}\sum_{i} x^{i}_{l,n} = \sum_{e}\sum_{i} y^{i}_{n,e}, \forall n \in N \quad (6)$$

$$\sum_{n}\sum_{i} y^{i}_{n,e} = \sum_{j}\sum_{i} z^{i}_{e,j}, \forall e \in DC \quad (7)$$

$$T_{j1} \le T_j \le T_{j2}, \forall j \in CM \quad (8)$$

$$u_n \in \{0,1\}, n \in N \quad (9)$$

$$v_e \in \{0,1\}, e \in DC \quad (10)$$

$$x^{i}_{l,n} \ge 0, y^{i}_{n,e} \ge 0, z^{i}_{e,j} \ge 0 \quad (11)$$

Objective function (1) is to maximize total profit computed by subtracting total cost from total revenue. Total income is simply the total selling income. Total cost includes operation cost, transportation cost.

TABLE 2 : Set of the parameters and variables

Sets
L set of suppliers
N set of available plants
DC set of available distribution centers
CM set of customers' market
TM set of transport mode
Parameters
S_l supply capacity of Supplier l
K_n production capacity of Plant n
F_n build and operation cost of Plant n
W_e process capacity of Distribution Center e
H_e build and operation cost of Distribution Center e
D_j demand quantity in Customer Market j
P_j product price in Customer Market j
$[T_{j1}, T_{j2}]$ response time interval in market zone j
$C^{i}_{l,n}$ unit transport cost from Supplier l to Plant n via transport mode i
$C^{i}_{n,e}$ unit transport cost from Plant n to Distribution Center e via transport mode i
$C^{i}_{e,j}$ unit transport cost from Distribution Center e to Customer Market j via transport mode i
$F(T_j)$ function between response time T_j in customer market j and sales income
$G(T_1, T_2, \cdots, T_j)$ function between all response time T_j and total cost of supply network
Variables
$x^{i}_{l,n}$ transportation amounts from Supplier l to Plant n via transport mode i

$y^i_{n,e}$	transport amounts from Plant n to Distribution Center e via transport mode i
$z^i_{e,j}$	transportation amounts from Distribution Center e to Customer Market j via transport mode i
u_n	decided whether building Plant n or not
v_e	decided whether building Distribution Center e or not
T_j	response time in customer market j

Constraint (2) prevents a supplier to exceed the maximal capacity.
Constraint (3), (4) ensure that plant and distribution center can provide enough goods.
Constraint (5) states that all products transferred to customers should be more than their demands in any market zone.
Constraint (6), (7) is related to flow conservation at plants and distribution center.
Constraint (8), (9), (10), (11) restrict the variables value from taking the interval, binary, and non-negative value etc.

A hybrid intelligent optimization algorithm for solving MINLP model

Obviously, the model is an MINLP problem. As a very complex and challenging one, MINLP has been proved to be NP-hard problem. Nevertheless, it can be solved with the computation technology development. The solving algorithms for MINLP can be categorized into three types: B&B, GBD and OA, while they need a long time as the size of MINLP problem is enlarged[17].

For the model described above, we try to design a hybrid algorithm taking full advantage of CPlex software and intelligent optimization methods such as GA (genetic algorithm) since we can transfer the model into a. The main procedures of the algorithm are as below:

1. Input the maximum iterations and other parameters in GA.
2. Initialize the binary variables in the model which are coded using 0-1 string in GA.
3. Given the binary variables' value, call CPlex solver to solve the model and get the objective function value, the solution of the model.
4. Execute selection, reproduction, crossover and mutation in GA for the solutions to get the new solutions.
5. Decide whether the convergence criterion can be met. If met, global solution is exported, the algorithm terminates. Else, return (4) to continue.

ILLUSTRATIVE EXAMPLE

Parameters especially for transport modes

In order to illustrate the model application, an illustrative example and its data in the paper[16] is referenced for the improved model. What's more, the transportation unit cost is provided as follows: S, F, DC, CM represents supplier, Factory, distribution center, customer market respectively. Tm1, Tm2 are different transport modes.

TABLE 3 : Transportation unit cost between facilities

Facility	Tm1	Tm2	Facility	Tm1	Tm2
S1->F1	200	300	F2->DC1	400	300
S1->F2	400	500	F2->DC2	100	200
S1->F3	300	600	F2->DC3	300	300
S2->F1	200	100	F3->DC1	600	400

S2->F2	100	150	F3->DC2	400	450
S2->F3	400	300	F3->DC3	200	250
S3->F1	800	750	DC1->CM1	900	800
S3->F2	600	500	DC1->CM2	800	850
S3->F3	100	150	DC2->CM1	600	700
F1->DC1	200	250	DC2->CM2	1000	900
F1->DC2	500	400	DC3->CM1	1000	1200
F1->DC3	700	600	DC3->CM4	900	800

Optimization results comparison

For comparison with the model in the paper[9], response time T_1, T_2 is set 1, 4 respectively. Using the hybrid algorithm, the optimal results are demonstrated in TABLE 4 which is same as the solutions in GAMS software.

TABLE 4 : Optimal solution of improved model

Item	Value
Profit	*30590000*
Supplier1->Factory2(Tm1)	350
Supplier1->Factory3(Tm1)	100
Supplier2->Factory2(Tm1)	150
Supplier3->Factory3(Tm1)	300
Factory2->DC2(Tm1)	500
Factory3->DC1(Tm2)	*0*
DC1->Market2(Tm1)	*400*
DC2->Market1(Tm1)	*450*
DC2->Market2(Tm2)	*50*

As TABLE 4 depicts, the profit is increased to 30590000 which is more than the previous model and goods transferred from plant 3 to distribution center 1 and from distribution center 2 to market 2 is via transport mode 2. This reveals that this improved model can get a better result by considering transport mode impacts. So, the model's effectiveness and the hybrid algorithm's feasibility are confirmed by this illustrative example.

CONCLUSIONS

Supply chain network design is one of the most important strategic decisions in the current competitive business environment. This paper firstly introduces a mixed integer nonlinear programming model considering response time and finds it can easily get an optimal solution using Cplex in Excel instead of Lingo software. Based on this original model, an improved model is proposed considering transport mode affecting response time and a hybrid algorithm is put forward. Finally, a numerical example has been solved to illustrate the proposed model's effectiveness and the solving algorithm's feasibility.

The improved model in this paper can be extended by considering some environmental aspects such as CO2 emissions to be a multi-objective optimization model. Another direction is to consider response time to customer requirements which need a tradeoff for supply chain network. Also it is suggested to increase the computation efficiency for large scale problems, some novel heuristic methods for this specific class of problems can be taken into account as the further step of this research.

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