Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 13 (11): 1988-1991, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.1988.1991

Low Carbon Distribution Center's Location Decision Method under Carbon Emissions Constraint Condition

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Abstract: This study established the calculate formula of 3 levels distribution system's carbon emissions and composed it with Baumol-Wolf model. Finally, this study built a low carbon distribution center location decision model with multi-suppliers, multi-distribution centers, multi-consumers and multi-kinds of commodities. At last, this study validated the model by an application case by using LINGO 11.

Key words: Low carbon constraint, distribution center, location decision

INTRODUCTION

In recent years, people widely concern the development of low carbon logistics. Sundarakani *et al*. (2010) studied the carbon footprint in the whole supply chain and gave the carbon reduction proposals in the logistics process (Sundarakani *et al*., 2010). The consensus is that the low carbon logistics system's all links, especially transportation system and distribution system, need to strengthen the carbon emission reduction. Article (Benjaafar *et al*., 2013) studied the effect of different carbon emissions of different location of shops, factories and distribution center and gave some reasonable facilities layout that can be the least carbon emissions.

There are many distribution center or warehouse's location models. The traditional methods includes integer programming, 0-1 programming and dynamic programming (Aikens, 1985) and branch and bound method (Holmberg, 1999) and mixed integer programming with inventory cost, fixed cost and transportation cost (Barahona and Jensen, 1998) and gravity method (Wang, 2012). The intelligent algorithms include the ant colony optimization algorithm (Li *et al*., 2012) and the particle swarm optimization algorithm (Sun and Wang, 2012). These intelligent algorithm models didn't specifically consider carbon emission constraints. In order to research low carbon distribution center's location, (Yang and Lin, 2011) discussed the distribution center's location decision model by combining with the carbon tax and carbon trading.

These studies took into account the carbon constraints but failed to establish a synthetic decision model for location of distribution center of low carbon. Therefore, on the basis of Baumol-Wolfe model, this study joins the carbon emission constraints and builds a comprehensive location decision model with carbon emissions by improving the Baumol-Wolfe model.

METHODOLOGY

Basic hypothesis: Distribution network composed of 3 level nodes, including suppliers, Distribution Centers (DC) and consumers. (2) The distribution centers' locations, fixed costs and capacity are all known. (3) Transport costs are direct proportional to the amount of commodities and the transport rate for the unit of commodity is known. (4) Carbon emissions are direct proportional to the traffic volume and the carbon emission rate of a unit of traffic volume is known. (5) A consumer only corresponds to a distribution center.

Distribution center's carbon emissions calculate model: Suppose the distribution system has i suppliers, j distrubition centers, k consumers and h kinds of commodities, the calculation formula of carbon emissions g show as Eq. 1:

$$g = T\sum_{i,j,k} dd_{ij}x_{ijh} + T\sum_{j,k,h} uu_{jk}D_{kh}z_{jk} + T\sum_{j} p_j(wj)^{\theta} + T\sum_{j} E_j r(w_j) \quad (1)$$

In which:

$$r(w_i) = \begin{cases} 0, (w_i = 0) \\ 1, (w_i > 0) \end{cases}$$

is the fixed cost coefficient; dd_{ij} is the carbon emission of the transport volume with a unit of commodity from supplier i to DC j; uu_{jk} is the carbon emission of the

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transport volume with a unit of commodity from DC j to consumer k; z_{jk} used to represent the consumer k whether distributed by the DC j and the value of 0 or 1; D_{kh} is the consumer k's expected demand for commodity h; p_j is DC j's carbon emissions of the transport volume with a unit of commodity;

$$w_j = \sum_i \sum_h x_{ijh}$$

is DC j's transport volume. E_i is DC i's fixed carbon emissions.

Improved baumol-wolfe model by adding constraint condition of carbon emissions: Combination Eq. 1 with baumol-wolf model, we can get the Eq. 2:

$$\min F = \sum_{i,h}(A_{ih}\sum_j x_{ijh}) + \sum_{i,j,h} C_h L_{ij} x_{ijh} + \sum_j F_j U_j + \sum_{j,h} B_{ih} Q_{jh}{}^{\alpha} + \sum_{j,k,h} d_h G_{jk} D_{kh} z_{jk} + T\sum_{i,j,k} dd_{ij} x_{ijh} + T\sum_{j,k,h} uu_{jk} D_{kh} z_{jk} + T\sum_j p_j (wj)^{\theta} + T\sum_j E_j r(w_j) \quad (2)$$

Equation 2's constrain conditions are shown as the following:

$$\sum_{j\in J} x_{ijh} \le S_{ih}$$

$$\sum_{j\in J} x_{ijh} \le \sum_{k\in K} D_{kh}$$

$$\sum_{i\in I}\sum_{h\in H} \lambda_h x_{ijh} \le M_j U_j.$$

$$\sum_{j\in J} U_j \le N$$

$$G_{jk} U_j z_{jk} \le Y$$

$$\sum_{i\in I} x_{ijh} \le M_j U_j$$

$$\sum_{j\in J} z_{jk} = 1$$

$$OU_j \ge \sum_{k\in K} z_{jk}$$

$$Q_{jh} = \sum_{i\in I} x_{ijh}$$

$$U_j = 0, 1$$

$$z_{jk} = 0, 1$$

$$x_{ijh} > 0 \text{ and must be an integer}$$

In Eq. 2, F is total cost and weight coefficient is α, θ ($0<\alpha<1$, $0<\theta<1$) and:

$$r(w_i) = \begin{cases} 0, & (w_i = 0) \\ 1, & (w_i > 0) \end{cases}$$

is fixed cost coefficient.

The unknown variables in Eq. 2: x_{jih} is the commodity h's volume of transport from supplier i to DC j; u_j presents whether the DC j is selected and the value is 0 or 1; z_{jk} presents whether the consumer k is distributed by the DC j and the value is 0 or 1.

The parameters in Eq. 2: I is the set of suppliers and J is the set of DCs and K is the set of consumers and H is the set of commodities and O is the number of consumers; A_{ih} is the supplier i cost of a unit commodity h; c_h is the transport fee for a unit commodity in the unit distance from supplier to DC; d_h is the distribution fee for a unit commodity in the unit distance from DC to consumer; F_j is the selected DC's total cost; B_{jh} is the unit commodity's distribution process costs of DC j; D_{kh} is the consumer k's expected demand for commodity h; S_{ih} is the largest supply the commodity's capacity of supplier i; M_j is the DC j's capacity; λ_h is the commodity h's capacity coefficient; L_{ij} is the distance from supplier i to DC j; G_{jk} is the distance from DC j to consumer k; Q_{jh} is the freight traffic volume in DC h; N is the maximum number of distribution centers; Y is the maximum distance from DCs to consumers; dd_{ij} is the carbon emission of the transport volume with a unit of commodity from supplier i to DC j; uu_{jk} is the carbon emission of the transport volume with a unit of commodity from DC j to consumer k; p_j is DC j's carbon emissions of the transport volume with a unit of commodity:

$$w_i = \sum_i \sum_h x_{ijh}$$

is DC j's transport volume:

$$r(w_i) = \begin{cases} 0, & (w_i = 0) \\ 1, & (w_i > 0) \end{cases}$$

is the fixed cost coefficient; E_i is DC i's fixed carbon emissions; T presents carbon tax.

APPLICATION CASE

A distribution system includes 4 suppliers, 2 kinds of commodities, 6 distribution center and 10 consumers. The basic data of commodities, supplier to DC and DC to consumer are shown as Table 1-3.

Table 1: Commodities' characteristic parameters

	Capacity coefficient λ m^3/piece	Transport rates c $/piece	Distribution rate cd$/piece•km
Commodity 1	0.4	20	18
Commodity 2	0.7	27	25

Table 2: From suppliers to DCs' parameters

L_{ij}/km	DC 1	DC 2	DC 3	DC 4	DC 5	DC 6	A_{ih}/piece	S_{ih}/piece
supplier 1	10	12	21	14	18	17	120/150	70/60
supplier 2	9	16	14	15	11	16	140/130	50/90
supplier 3	13	11	2	17	8	15	90/130	80/60
supplier 4	9	13	20	18	12	11	160/120	75/95
B_{jh}/$	70/60	65/50	76/74	80/55	74/53	60/80		
M/m^3	100	150	120	160	110	155		
F_j/$	50000	75000	60000	85000	54000	75400		

Table 3: From DCs to consumers' parameters

	Consumers									
G_{jk}/km	1	2	3	4	5	6	7	8	9	10
DC 1	5	4	7	9	3	6	10	12	8	5
DC 2	3	9	6	8	4	13	14	5	7	6
DC 3	8	10	7	5	7	2	2	7	3	4
DC 4	9	3	1	8	11	2	6	3	7	9
DC 5	7	5	9	10	2	3	1	7	6	5
DC 6	3	2	4	8	6	5	9	10	12	7
D_{kh}/piece	15/24	20/18	18/21	19/17	6/13	17/24	23/17	18/30	25/21	11/15

Table 4: Unit carbon emissionfrom suppliers to DCs

dd_{ij}/kg	DC1	DC2	DC3	DC4	DC5	DC6
Supplier 1	10	12	15	14	20	16
Supplier 2	12	16	10	9	14	15
Supplier 3	18	13	14	17	10	9
Supplier 4	10	16	19	16	11	12

Table 5: Unit carbon emission from DCs to consumers

	Consumers									
uu_{jk}/kg	1	2	3	4	5	6	7	8	9	10
DC1	12	5	11	8	5	10	11	10	12	9
DC2	14	14	6	9	4	7	4	5	11	7
DC3	15	15	13	6	7	2	10	8	7	6
DC4	9	7	7	2	6	5	12	5	4	10
DC5	10	8	12	11	9	9	15	9	6	8
DC6	11	5	10	8	7	4	9	12	10	7

Table 6: Unit variable carbon emission and fixed carbon emission in DCs

	DC1	DC2	DC3	DC4	DC5	DC6
$p_{j/kg}$	120	180	140	150	120	130
$E_{j/kg}$	150	140	170	140	120	150

Table 7: The number of commodity 1 and commodity 2 in suppliers

	Commodity 1/Commodity 2			
Unit: piece	Supplier 1	Supplier 2	Supplier 3	Supplier 4
DC1	70/0	0/0	0/0	0/91
DC3	0/0	22/49	80/60	0/0

Table 8: Distribution schemes of commodity 1 and commodity 2

	Consumers (Commodity 1/Commodity 2)									
Unit: piece	1	2	3	4	5	6	7	8	9	10
DC 1	15/24	20/18	18/21	0/0	6/13	0/0	0/0	0/0	0/0	11/15
DC 3	0/0	0/0	0/0	19/17	0/0	17/24	23/17	18/30	25/21	0/0

Carbon emissions' data is shown as Table 6.

Putting the data from Table 1 to 6 into the Eq. 2 and using LINGO 11 to solve the model, we can get the distribution system's optimal solution. The results show that DC1 and DC3 are selected. The distribution schemes are showed as Table 7-8.

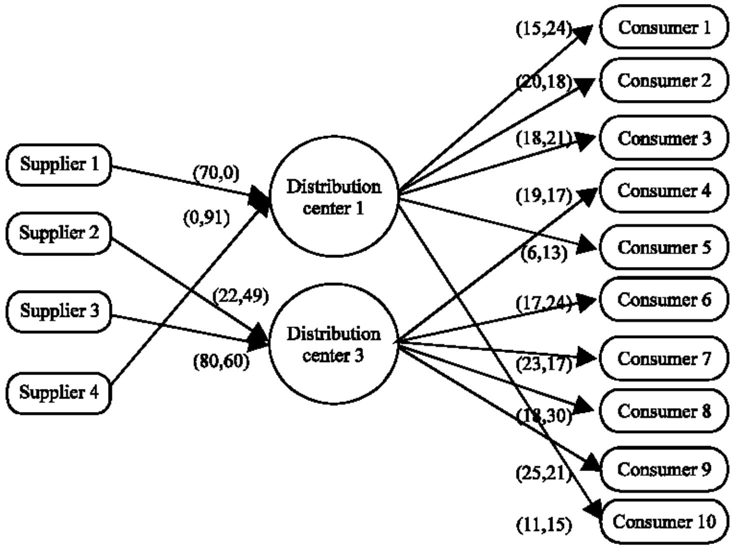

Fig. 1: Final distribution scheme

The final distribution scheme can satisfy all the consumers' demands and can meet the constraints of scale and production capacity, shown as Fig. 1.

The final distribution system's minimum cost is 368930.6 $ and the carbon emissions is 107240 kg.

CONCLUSION

- This study's subject is 3 levels distribution system and it has multi-suppliers, multi-distribution centers, multi-consumers and multi-kinds of commodities
- This study established the calculate formula of 3 levels distribution system's carbon emissions and composed it with Baumol-Wolf model
- This study's model introduced the carbon tax factor and achieved the desired emission control targets in the assumption of the minimum total cost

ACKNOWLEDGMENTS

Project supported by National Natural Science Fund of China (No. 71071054) and the Fundamental Research Funds for the Central Universities of China (No. 11QR34).

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