Transportation Research Part D 22 (2013) 45–48

Contents lists available at SciVerse ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

A multi-objective optimization model for sustainable logistics facility location

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ARTICLE INFO

Keywords:
Sustainable facility location
Service reliability
Carbon dioxide emissions

ABSTRACT

This paper offers an exploratory study of sustainable facility location. The methodology, based on the classical uncapacitated facility location problem, provides decision makers with a multi-objective optimization model to determine the trade-off among economic, service and environmental considerations. Our results indicate that it may be desirable to open more facilities than optimal from a narrow economic perspective to reduce the carbon dioxide emissions of transport and to improve service reliability.

1. Introduction

Road freight transport has been a rapidly growing contributor to carbon dioxide (CO_2) emissions (European Commission, 2010). Logistics system design models have traditionally focused on minimizing economic cost or maximizing customer service level without taking CO_2 emissions into account. Recent studies, however, started to address the challenging requirements of sustainable facility location.

This paper develops a multi-objective uncapacitated facility location problem (UFLP) with an environmental objective in the context of sustainable development. The model is to simultaneously minimize economic cost, CO_2 emissions, and maximize service reliability by strategically locating facilities within a logistics network.[1]

2. Model formulation and solution algorithms

2.1. Formulation of the model

The UFLP is a classical facility location problem and forms the basis of many location models that have been used in logistics network design. Its finds the best location of facilities and the allocation of customers that minimizes transportation and fixed costs (Daskin et al., 2003).

To be competitive, logistics service providers need to offer suitable levels of service to customers, and this is often related to facility location layouts, distances from customers to facilities, time requirements for delivering goods, the capability of facilities to supporting customer' demands, and the connectivity of transportation routes.

Here, customer service reliability is defined as the probability of one facility providing the required goods to customers within a given time given a set of constraints. One of the constraints considered is the need to limit CO_2 emissions. While there are a number of factors affecting emissions levels, we only consider the amount of goods being transported and the

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[1] For recent work in this field see, Chaabane et al. (2011) and Elhedhli and Merrick (2012).

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http://dx.doi.org/10.1016/j.trd.2013.03.003

distance travelled assuming, road vehicles are identical, that average speed is known, and the gradient of a road is not a factor.

Based on the UFLP, the problem is formulated as a mixture of three mathematical programming formulations: minimum economic cost, maximum customer service reliability and minimum CO_2 emissions. We define the indices $i = 1, 2,\ldots, I$ and $j = 1, 2,\ldots, J$ as corresponding to customers and candidate facilities; each customer having a demand h_i. A logistics facility at location j has a fixed cost f_j. The unit cost of shipping from a facility at location j to customer i is c_{ij}. The distance between a facility at j and customer i is d_{ij}. The speed of trucks shipping from facilities to surrounding customers is modeled as a random variable v with a distribution function $F_v(\cdot)$. T_i is the time deadline of customer i; e_{vf} is the CO_2 emissions of a fully loaded vehicle; e_{ve} is the CO_2 emissions of an empty vehicle, and w is the weight limit for a vehicle. Two binary location variables are introduced; X_j taking the value one if a facility is open at candidate location j and zero otherwise; Y_{ij} takes a value of one if customer i is assigned to facility j and zero if not. The model can be formulated as:

$$Min \quad \sum_{j=1}^{J} f_j X_j + \sum_{j=1}^{J}\sum_{i=1}^{I} c_{ij} h_i d_{ij} Y_{ij} \tag{1}$$

$$Max \quad Min\{(1 - F_v(d_{ij}/T_i))Y_{ij}\} \tag{2}$$

$$Min \quad \sum_{j=1}^{J}\sum_{i=1}^{I} d_{ij}[(\varepsilon_{vf} - \varepsilon_{ve})h_i/w + \varepsilon_{ve}\lceil h_i/w \rceil]Y_{ij} \tag{3}$$

$$S.t. \quad \sum_{j=1}^{J} Y_{ij} = 1 \quad \forall i \tag{4}$$

$$Y_{ij} \leqslant X_j \quad \forall i,\ j \tag{5}$$

$$X_j \in \{0, 1\} \quad \forall j \tag{6}$$

$$Y_{ij} \in \{0, 1\} \quad \forall i,\ j \tag{7}$$

The objective function (1) minimizes the sum of fixed location and transportation costs. The objective function (2) maximizes minimum service reliability and function (3) minimizes CO_2 emissions from transportation. Constraints (4) guarantee that each customer is assigned to exactly one logistics facility, and constraints (5) state that a customer cannot be assigned to a facility unless it is open. Constraints (6) and (7) are standard integrality constraints.

2.2. The hybrid algorithm

A classical technique is utilized to solve the multi-objective optimization problem, which applies the ε-constraint method. From the perspective of sustainable development, the environmental impact is considered as the priority, with the economic and the service objectives formulated as constraints. After transforming the multiple objectives into one, the greedy heuristic is used to construct a feasible solution by greedily dropping facilities from the solution until no further improvement can be obtained. In detail, the procedure is:

Step 1: let the current number of facility locations $k = J$, that is, exists facilities at all candidate sites.
Step 2: allocate each customer to the nearest facility among k facility locations, and compute the CO_2 emissions and the cost and the service reliability to each customer.
Step 3: if the economic cost is lower than the decision maker's expectation, and the service reliability is higher than the specified limit, stop and return the last results; otherwise, go to *Step 4*.
Step 4: select one facility and ensure that the increase in CO_2 emissions is smaller than if its customers are reallocated to other nearby facilities, while guaranteeing that the economic cost and service reliability satisfy the decision makers.
Step 5: drop the facility from the solution and let $k = k - 1$, then go to *Step 2*.

Table 1
The demand of each customer location.

Customer location	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}
Demand (ton)	166	156	88	59	163	191	79	141	99	170	159	50	176	199	113	180	126	48	56	93	155	169	162	77	116