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# Solving a capacitated fixed-charge transportation problem by artificial immune and genetic algorithms with a Prüfer number representation

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ABSTRACT

This paper presents a mathematical model for a capacitated fixed-charge transportation problem in a two-stage supply chain network, in which potential places are candidate to be as distribution centers (DCs) and customers with particular demands. In contrast with the previous studies considered ample capacity for DCs, we consider the capacity for each DC. The presented model minimizes the total cost in such a way that some DCs are selected in order to supply demands of all the customers. To tackle such an NP-hard problem, we propose an artificial immune algorithm (AIA) and a genetic algorithm (GA) based on the spanning tree and Prüfer number representation. We introduce a new method to calculate the affinity value by using an adjustment rate. Furthermore, we apply the Taguchi experimental design method to set the proper values of AIA and GA parameters in order to improve their performances. Finally, we investigate the impact of increasing the problem size on the performance of our proposed algorithms.



## 1. Introduction

Supply chains (SCs) are generally complex and characterized by numerous activities spread over multiple functions and organizations (Arshinder & Deshmukh, 2008). SC is a worldwide network of suppliers, factories, warehouses, distribution centers, and retailers through which raw materials are acquired, transformed, and delivered to customers (Fox, Barbuceanu, & Teigen, 2000). It has evolved very rapidly since 1990s showing an exponential growth in the literature (Burgess, Singh, & Koroglu, 2006). Thomas and Griffin (1996) provided an extensive review and discussion of the supply chain literature. They pointed out that for many products logistics expenditures can constitute as much as 30% of the net production cost. In the last decade, there have been many researchers reported new models or methods to determine the transportation or logistics activities that can give the least cost (Gen & Cheng, 1997, 2000). There is no doubt that logistics is an important function of business that evolves to strategic supply chain management (New & Payne, 1995).

Logistics is often defined as the art of bringing the right amount of the right product to the right place at the right time, and it usually refers to supply chain problems (Tilanus, 1997). One of important factors which influences on a logistic system is to find out the number of distribution centers (DCs). The transportation network design is one of the most important fields of supply chain management (SCM) that offers great potential to reduce costs. The transportation problem (TP) is a well-known basic network problem that was originally proposed by Hitchcock (1941). A basic assumption in any transportation problem is that the transportation cost is directly proportional to the number of units transported (Diaby, 1991). Many practical transportation and distribution problems can be modeled as fixed cost transportation problems (Adlakha & Kowalski, 1999; Sun, Aronson, Mckeown, & Drinka, 1998). In this paper, we consider two stages of a supply chain network, namely distribution centers (DCs) and customers, as shown in Fig. 1. There are potential places, which are candidate to be as distribution centers (DCs), and customers with particular demands. Each of the potential DC is served from a manufacturer and can ship items to any of the customers. It is assumed that the manufacturer has no capacity limitation in production.

In the previous studies, it was assumed that each potential DC has ample capacity. To be more realistic, we assume that each potential DC has distinct capacity in order to support the customers (i.e., each DC may have different capacity). In this paper, we also consider a transportation cost from the manufacturer to DCs and an opening cost for each potential DC. The presented model minimizes total cost with selecting some potential places as distribution centers which supply demands of all the customers. The

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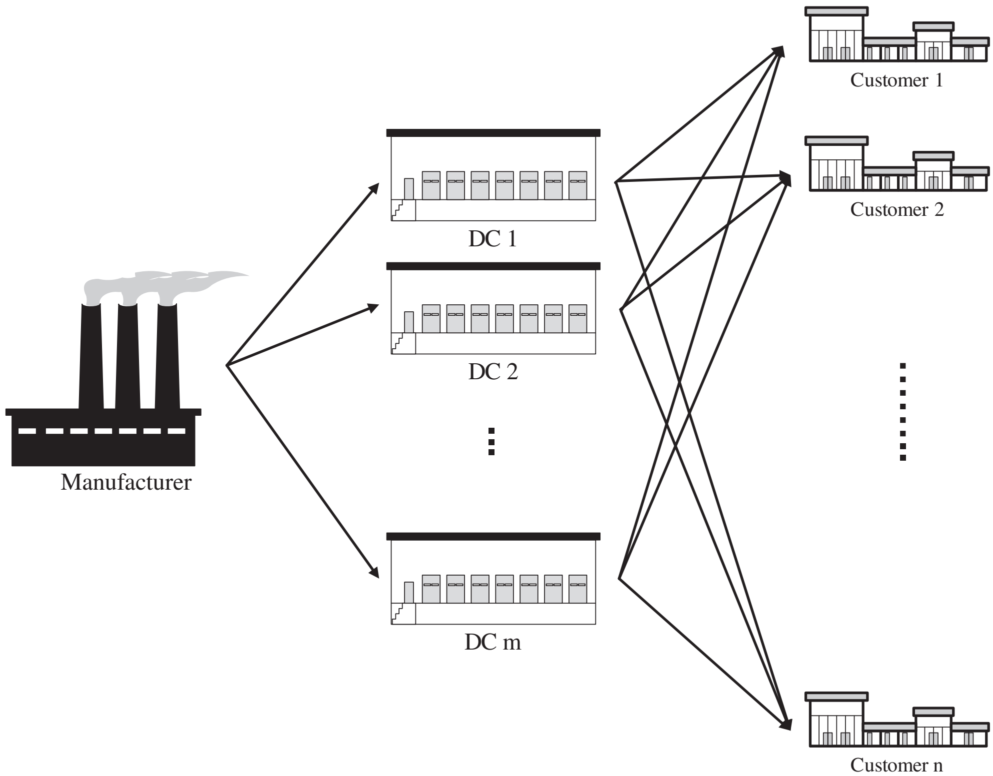


**Fig. 1.** Two-stage supply chain network.

total cost considers transportation cost from manufacturer to DCs, opening cost for each potential DC, transportation cost from DCs to the customers, and fixed cost for transportation from DCs to customers. To find the best solution, we attempt to use the spanning tree-based genetic algorithm (GA) and artificial immune algorithm (AIA). It is known that the effectiveness of a GA highly depends on the great choice of the encoding scheme, selection, crossover operator, mutation operator, and the related GA parameters (Ruiz & Maroto, 2006). We apply the Prüfer number (Prüfer, 1918) encoding that is the one of the popular tree encoding schemes (Gen & Li, 1998; Li & Gen, 1997; Li, Gen, & Ida, 1998; Zhou, Min, & Gen, 2002). This encoding is known to be an efficient way to represent various network problems (Zhou & Gen, 1997). The use of the Prüfer number representation for such problems was introduced by Gen and Cheng (1997). They utilized this number, in which it is capable of equally and uniquely representing all possible trees in a network graph (Gen & Cheng, 2000). They found that the use of the Prüfer number is more suitable for encoding a spanning tree, especially in some research fields, such as some extended transportation problems (Syarif & Gen, 2003), production/distribution problems (Gen & Syarif, 2003; Syarif, Yun, & Gen, 2002), minimum spanning problems (Gen & Cheng, 2000; Jo, Li, & Gen, 2007; Syarif & Gen, 2003; Zhou, Min, & Gen, 2002).

The rest of this paper is as follows. The next section describes the mathematical model and its descriptions. Our proposed algorithms are explained in Sections 3 and 4. In Section 5, experimental results are presented. Finally, in Section 6, conclusions are provided and some areas of further research are then stated.

## 2. Mathematical model and descriptions

In this model, there are $m$ potential DCs and $n$ customers with particular demands. Each of the $m$ potential DCs can ship demands to any of the $n$ customers at a shipping cost per unit $c_{ij}$ (i.e., unit cost for shipping from distribution center $i$ to customer $j$) plus an opening cost, $f_i$, assumed for opening potential DC $i$. Also, there are transportation cost from manufacturer to DCs, $c_i$, and fixed cost for transportation from DCs to the customers, $f_{ij}$. The objective is to find which candidate places are to be opened as distribution centers and which customers are served from opened distributers so that the total cost is minimized. On the other hand, in this problem finding the minimum system cost, we want to specify that each customer receives its demands from which distribution center. Notations and the mathematical model are presented as follows.

| | |
|---|---|
| $x_{ij}$ | Known quantity to be transported on the route $(i,j)$ from distributer $i$ to costumer $j$ |
| $c_{ij}$ | Shipping cost per unit from distributer $i$ to costumer $j$ |
| $f_i$ | Opening cost assumed for opening potential DC $i$ |
| $c_i$ | Transportation cost from manufacturer to DC $i$ |
| $a_i$ | Capacity of DC $i$ |
| $b_j$ | Number of units demanded at costumer $j$ |

$$\min \quad Z = \sum_{i=1}^{m}\sum_{j=1}^{n}(c_{ij}x_{ij} + f_{ij}y_{ij}) + \sum_{i}^{m} c_i\left(\sum_{j}^{n} x_{ij}\right) + f_i y_i$$

$$\text{s.t} \quad \sum_{i=1}^{m} x_{ij} = b_j; \quad j = 1,\ldots,n \tag{1}$$

$$\sum_{j=1}^{n} x_{ij} \leqslant a_i; \quad i = 1,\ldots,m \tag{2}$$

$$X_{ij} \geqslant 0; \quad \forall i,j \tag{3}$$

$$y_{ij} = \begin{cases} 1 & x_{ij} \geqslant 0 \\ 0 & x_{ij} = 0 \end{cases} \forall i,j \tag{4}$$