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The double layer optimization problem to express logistics systems and its heuristic algorithm

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ABSTRACT

With the rapid development of information technologies, it is very urgent to reform the modern express logistics system via these advanced technologies. For this reason, the double layer optimization problem is proposed to express logistics systems. Also, the heuristic method is constructed to this proposed problem. Experimental results suggest that the proposed model and heuristic are feasible and correct.

1. Introduction

With the development of economic globalization, the market competition constantly changes (Yao and Xing, 2012; Li and Xing, 2012; Sun et al., 2012). Express service has become one of the fastest-growing industries in China. Until 2009, there are more than 2000 express enterprises and 7000 branches. Although Chinese express industry develops fast, there is still a large gap compared with that in advanced countries. The Chinese economic aggregate ranks the world third, but the postal business is far behind. This cannot meet the needs of economic development level. The Chinese express industry still has many problems to be solved.

In 'Logistics Industry Restructuring and Revitalization Plan' issued by the Chinese State Council, it focuses on updating and reforming the modern logistics industry by information technology. This embodies the concept of 'big logistics' and the idea of impelling the information sharing and resource integration among logistics enterprises. In this paper, the 'big logistics' refers to the distribution of information and the sharing of resources of logistics (fleet, warehouse and personnel) of logistics companies and third-party logistics companies. This sharing will guarantee a greater extent the usage of social resources, reduction of total logistics expenditures and operating costs. Only the idea of 'big logistics' is established that the resource utilization can be implemented to the utmost, the logistics expenses and the operating costs are reduced. At the same time, the integrated model which considers the macro allocation problem of logistics system and the fast distribution problem for express items was seldomly studied. For this reason, the double layer optimization problem is proposed to express logistics systems. Also, the heuristic method is constructed to this proposed problem.

2. Literature review

The routing optimization problem can be divided into two types. One is the vehicle routing problem (VRP) that provides services for points, such as the commodity distribution to chain supermarkets. Another one is the arc routing problem (ARP) that provides services for roads, i.e., the watering cart routing problem. The express logistics system optimization problem is a kind of capacitated arc routing problem (CARP).

2.1. Existing methods to the CARP

The CARP is an NP-hard optimization problem and exact approaches, such as branch-and-bound (Hirabayashi et al., 1992), can deal with only very small instances of 20–30 edges (Lacomme et al., 2004). Subsequently, heuristics are required for solving larger problem instances. Examples include augment-merge (Golden and Wong, 1981), path-scanning (Golden et al., 1983), construct-and-strike (Pearn, 1989), Ulusoys tour splitting algorithm (Ulusoy, 1985) and Augment-Insert (Pearn, 1991). Although these heuristics generally produce fairly good results, better results can be obtained by meta-heuristics (Feng et al., 2010; Mei et al., 2009; Ong et al., 2010; Tang et al., 2009).

Beullens et al. proposed the Guided Local Search (GLS) method for the CARP (Beullens et al., 2003). The GLS was extended by some new moves (relocate, exchange and cross) and also made use of lists of neighbors and edge marking. Experiments on standard benchmark problems demonstrate that the GLS finds all the best known upper bounds and also improved the bounds for some of the instances. On a set of new benchmark problems, the GLS consistently produced high quality solutions and in many cases located the optimal solution.

Doerner et al. employed an ant colony optimization (ACO) to deal with the CARP (Doerner et al., 2004). Experimental results

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obtained from 23 instances generated by DeArmon (1981) show that the ACO algorithm is superior to Tabu Scatter Search (Greistorfer, 2003) and CARPET (Hertz et al., 2000), but inferior to Lacomme's memetic algorithm (Lacomme et al., 2004). Hertz and Mittaz developed the Variable Neighborhood Descent (VND) method for the CARP (Hertz and Mittaz, 2001) and tested it on 23 instances generated by DeArmon DeArmon (1981), 34 instances by Benavent et al. (1982), and 270 instances produced by Hertz et al. (2000). The results demonstrate that CARPET and VND are superior to a range of simple heuristics. Polacek et al. proposed a Variable Neighborhood Search (VNS) for the CARP with intermediate facilities (Polacek et al., 2008). The VNS is a simple and robust method which tackles the CARP as well as some of its extensions. This VNS displays an excellent performance on four different sets of benchmarks. Hertz et al. constructed a Tabu Search (TS) heuristic for the CARP (Hertz et al., 2000), while Brando and Eglese developed a deterministic Tabu Search Algorithm (TSA) for the CARP (Brando and Eglese, 2008). Mei et al. proposed an operator called Global Repair Operator (GRO; (Mei et al., 2009)) to address the major disadvantage encountered by most of the traditional algorithms: they inserted GRO to the TSA and apply the resultant Repair-based Tabu Search (RTS) algorithm to five well-known benchmark test sets. Experimental results suggest that RTS is competitive with a number of state-of-the-art approaches.

Lacomme et al. proposed several different evolutionary algorithms for the CARP (Lacomme et al., 2001, 2004, 2005, 2006). As mentioned in the introduction, Lacomme et al. proposed an extended CARP (Lacomme et al., 2004) which considered attributes such as mixed networks, parallel arcs and turn penalties. The authors also proposed a Memetic Algorithm (MA; (Lacomme et al., 2004)) and experimental results demonstrate that the MA outperforms a range of other heuristics on 81 instances with up to 140 nodes and 190 edges. The authors explain the algorithm's performance as follows: (1) individual solutions are strongly improved by local search, (2) small populations of distinct solutions tend to avoid premature convergence, (3) some good solutions are obtained using classical heuristics, and (4) the partial replacement technique used for restarts improve the solution quality of population.

Tang et al. proposed a Memetic Algorithm with Extended Neighborhood Search (MAENS; (Tang et al., 2009)). Unlike existing approaches, MAENS employs a novel local search operator called Merge–Split (MS) that is capable of large step sizes and thus has the potential to search the solution space more efficiently. Experimental results suggest that MAENS is superior to a number of state-of-the-art algorithms.

2.2. Other versions of the CARP

The amount of research directed towards the Multi-depot CARP (MCARP) is considerably less. Amberg et al. (2000) proposed a Tabu search using capacitated trees to solve the multiple center CARP. Li et al. proposed an improved genetic algorithm to the MCARP in 2009 (Li et al., 2009). Xing et al. (2009, 2010, 2011) constructed a novel evolutionary approach to the MCARP that integrates extended CARP heuristics into a novel evolutionary framework. Kansou and Yassine deal the MCARP with two different approaches: ant colony optimization combined with an insertion heuristic and memetic algorithm based on a special crossover (Kansou and Yassine, 2009, 2010). Their computational results on benchmark instances suggest the superiority of the memetic algorithm compared to the ant colony optimization (Kansou and Yassine, 2010).

The other extended versions of CARP problems include: periodic capacitated arc routing problems (Chu et al., 2005, 2006a, 2006b), splitdelivery capacitated arc routing problems (Belenguer et al., 2010), capacitated arc routing problems with intermediate facilities (Polacek et al., 2008), capacitated arc routing problems with time windows (Reghioui et al., 2007), capacitated arc routing problems with refill points (Amaya et al., 2007), capacitated arc routing problems with stochastic demands (Laporte et al., 2010), and so on.

All the existing methods developed for the CARP assume a predefined and fixed service architecture (i.e., the number and position of the depots and the number of vehicles is fixed). Motivated by practical requirements, an extended version of the traditional CARP is proposed in the next section where both the service scheduling (a set of vehicle routes) and the service architecture (a configuration of depots and vehicles) need to be optimized simultaneously to improve the quality of service.

3. Problem formulation

In fact, the express logistics system could mean different services (e.g. services for delivery, packaging, storage). In this paper, we mainly consider the service of delivery. The services for packaging and storage will be studied in the future. At the same time, we mainly consider the delivery from depot the customers, so it is reasonable to formulate the express logistics system as a type of capacitated arc routing problem.

In comparison with the extend CARP proposed by Lacomme et al. (2004), two important extensions are addressed in this work. The first extension considers the maximum service time: service time is defined as the vehicle's traveling time which is equivalent to the total time required by the vehicle to carry out the tasks assigned to it. The consideration of this aspect may lead to shorter overall service times. The second extension deals with the optimization of the service architecture which means that both the number and the position of depots are variable. This extension would guarantee the availability of services (the restriction on the service time places hard constraints on the problem: if the road network is large or the service time is small, some roads cannot be serviced because of their distance from the depot).

Our double layer optimization problem to express logistics systems (for short, ECARP) is modeled as the directed connected graph in which each arc has a deadheading (traveling without service) cost. A subset of arcs with known demands and additional service costs must be serviced by the vehicles. A penalty may be imposed depending on the sequence of arcs traversed. For instance, U-turns and left turns may incur a penalty. A fleet of identical trucks, each with the same purchase cost, capacity and speed are employed to service the arcs. The number of vehicles and depots is considered to be a decision variable. Every required arc is serviced by one single trip and each trip starts and ends at the same depot. The total demand of a trip must not exceed the vehicle's capacity. All services must finish within the maximum service time and no partial services are allowed. At any depot, the dispatched truck and resource must not exceed its own (the service capacity of each depot is considered). A solution consists of determining a configuration of depots and vehicles as well as a set of vehicle routes; the goal is to minimize the sum of fixed and running costs.

3.1. Preliminary knowledge

The symbols used in this section are summarized in Table 1. The following concepts are illustrated for the sake of clarity.

(1) Mixed connected graph: the mixed graph allows existing two kinds of links: undirected edges and directed arcs. In this work, a mixed connected graph is transformed into a directed connected graph through replacing each edge by two arcs with opposite directions.