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Optimising courier routes in central city areas

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ABSTRACT

Determining efficient routes for couriers in central city areas is becoming more challenging due to growing levels of congestion. New technologies allow on-street loading zones to be booked to reduce waiting times and circulation.

Couriers when planning deliveries need to consider both driving and walking routes to optimise their activities. A two-layer optimisation model has been developed for determining the best routes for minimising operating and environmental costs. A genetic algorithm is proposed to find (near-)optimal solutions. The output can provide guidance for couriers as well as planners who are involved in determining duration limits at loading zones.

1. Introduction

Rapid urbanization is leading to rising levels of demand for distribution of goods in cities that is creating many challenges (Taniguchi and Thompson, 2015). In many central city areas, construction of new infrastructure such as subways and light rail systems as well as residential towers are causing major disruption as well as reducing the amount of on-street loading bays that can be used by delivery vehicles.

Currently, couriers often experience congestion and delays accessing on-street loading zones when delivering goods (Iwan et al., 2017). This increases emissions, energy consumption and drivers' frustration. Also, drivers often have limited knowledge and experience regarding the location and availability of loading zones. Dense traffic and pedestrian networks with many one-way streets present significant challenges for carriers to undertake efficient deliveries (Jaller et al., 2013). The time taken while driving, unloading and walking as well as the distance travelled affect the productivity of distribution.

Couriers when delivering goods to customers in Central Business Districts (CBDs) often have difficulty finding suitable locations for unloading goods. Searching for available on-street loading zones can generate a significant amount of additional time for delivery routes as well as increasing traffic congestion.

Recent developments in sensor technologies such as presence detectors and GPS combined with internet and phone-based booking systems allow loading zones to be booked in real time (McLeod and Cherrett, 2011). There is a need to determine the best loading zones for delivery vehicles to use to minimise distribution costs. This will allow efficient routes to be identified and the impacts of deliveries in CBDs to be reduced.

Recent surveys undertaken in Sydney's CBD reveal that couriers often serve multiple customers from individual loading zones (Thompson et al., 2018). Thus, optimizing CBD distribution routes needs to incorporate both vehicle and walking routes. This paper describes a model developed for determining optimal courier routes that minimize delivery (or distribution) costs taking into account both vehicle and walking costs. The model incorporates a combination of modes (vehicular and active) that are required for CBD

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distribution. On-street loading zones are a key component of the interchange between these modes. Traffic paths used to access loading zones as well as the paths used to cart the goods to establishments are determined. The optimal combinations of both vehicle and pedestrian routes for distribution to a number of customers in a CBD are produced. The vehicle route consists of a sequence of loading zones to be used. From each loading zone a sequence of customers to be visited is also derived.

This courier routing problem is formulated and solved as a multi-objective two-layer programing optimisation model. In the upper layer, the choice and order of loading zones to be used are produced, and at the lower layer, the pedestrian routes are generated. The decisions made for the choices of loading zones and customers serviced at each loading zone affect each other. The objective function consists of the distances travelled by the vehicle and walking combined with their relative importance weightings. Constraints relating to maximum parking durations are also incorporated. To solve the model, a genetic-algorithm based search method is developed.

The paper is organized as follows. After a brief review of the literature in Section 2, Section 3 provides a formulation of the courier routing optimisation problem and a few variants with relaxation of some constraints. Section 4 presents a genetic-algorithm based approach to the multi-objective two-layer optimisation problem. Section 5 discusses the results of a case study for Melbourne CBD. The last section concludes the paper.

2. Literature review

2.1. Multi-objective optimization

The classical methods for solving multi-objective optimization are categorized into four types (Halter and Mostaghim, 2006): no preference methods, priori methods, progressive methods and posteriori methods. We use the weight-sum method (Marler and Arora, 2010), which is a priori method, to solve our problem.

2.2. Vehicle routing problem (Traveling salesman problem)

The upper-layer problem of selecting loading zones and their route can be considered as a combination of the facility location problem and the (asymmetric) traveling salesman problem (TSP) (Applegate, et al., 2006; Gutin and Punnen, 2006) (or vehicle routing problem (VRP) (Dantzig and Ramser, 1959)). The TSP and the VRP are well known in combinatorial optimization. Given the large amount of literature on those two topics, we refrain from extensive review of them. The location planning problem of urban consolidation centers (UCCs), also known as urban distribution centers (UDCs), is a particular facility location problem, which has been extensively studied to address the freight distribution problem in CBD areas (Allen, et al. 2012; Awasthi, et al., 2011; Klose and Drexl, 2005; Lee and Kwon, 2010; Muñzuri, et al., 2012; Yang et al., 2007). Optimal location problems of UCCs are discrete location models, which minimize the costs to serve demands with a given candidate locations (Taniguchi et al., 2001). We shall discuss UCCs and their studies that are more related to our problem later.

For the lower-layer problem, once the set of customers visited at each loading zone is chosen, the optimal route to visit all the customers provided the constraints of time and size/weight of goods are satisfied needs to be found. This becomes a capacitated vehicle routing problem (CVRP) (Achuthan and Caccetta, 1991; Ralphs et al., 2010) with time windows (VRPTW) (Baños et al., 2013; El-Sherbeny, 2010; Sousa et al., 2011). An overview on the VRPTW is provided in (El-Sherbeny, 2010), which discusses a number of exact, heuristic and meta-heuristic methods. Multi-objective functions of vehicle routing are considered in (Baños, et al., 2013; Sousa et al., 2011). In addition to minimizing the total traveling time/distance, (Baños, et al., 2013) considers minimizing the imbalance among routes using a simulated annealing algorithm, whereas (Sousa et al., 2011) penalizes the introduction of additional vehicles using mixed integer programming.

The problem considered in this paper shares some common properties with the Two-Echelon Vehicle Routing Problem (2E-VRP). In the 2E-VRP, freight distribution is broken into two levels via introducing intermediate logistic platforms as intermediate delivery points. Goods are first shipped from a warehouse/depot to logistic platforms, such as UCCs. After being consolidated, goods are further delivered from the platforms to customers (usually by electrical vehicles). The 2E-VRP often arises in supply chain management and inventory problems and takes into consideration traffic congestion in urban areas. Loading zones play, to some extent, a similar role to second-level logistic platforms, but are closer to urban mini-hubs discussed in (Muñzuri et al., 2012) compared to UCCs. UCCs are open during business hours. They require investment and operation costs, and therefore their number is limited. Loading zones are much more widely distributed especially in central city areas. They are usually free of charge but their availability is not guaranteed. An early study of the 2E-VRP was related to the city logistics (Crainic et al., 2004). The authors proposed a two-tier distribution structure using intermediate platforms, called satellites, for the freight distribution. Their subsequent work (Crainic et al., 2010) investigated the impact of parameters such as the number and location of customers and satellites and the travel cost between satellites and customers on the total distribution cost. Extensions of the classic 2E-VRP consider capacitated vehicles (2E-CVRP) (Feliu et al., 2011; Perboli et al., 2011; Santos et al., 2013) and also time dependent travel costs (Soysala et al., 2015). Gianessi et al. (2016a, 2016b) focused on a special case where UCCs are all connected by a ring structure. Most approaches to the (large-sized) 2E-VRP and 2E-CVRP are heuristics based, for example (Crainic et al., 2009; Feliu et al., 2011; Gianessi et al., 2016b; Soysala et al., 2015.). Other algorithms include branch-and-bound (Santos et al., 2013) and column-generation (Gianessi et al., 2016a).

The courier routing optimisation problem discussed in this paper has commonalities with 2E-VRPs, for example, the natural two-level structure. The choice of distribution centres, in this paper that is loading zones, plays a key role to the design of the delivery routes. Nevertheless, unlike other typical 2E-VRPs, the routing problems at both levels are explicitly considered and multiple travel

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