An improved Ant-Colony Optimization model for the Vehicle Routing Problem with Simultaneous Pickups and Deliveries: the case of a Mediterranean freight transport logistics company

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Abstract

Transport of goods plays a fundamental role in the logistics chain, often representing the major cost item for the logistics operator. By improving route assignments to the vehicles of the fleet, it is possible to obtain significant time and cost savings. This paper presents a novel Ant Colony Optimization model aimed at solving Vehicle Routing Problems with Simultaneous Pickups and Deliveries (VRPSPD), developed and implemented in a multi-agent simulation environment. The methodology is applied to the real case study of a logistics company in Italy in order to find an optimal set of routes able to transport palletized goods both from the main depot to different clients and from the clients to the depot, with the objective of minimizing the cost function related both to the travelled distance and to the fleet size. Different scenarios have been simulated to study the cost trend per load unit, deriving from the route optimization process, when the total demand (collection and distribution orders) varies, and also to evaluate the load-capacity use of vehicles. The findings highlight the validity of the method to optimize cost and scheduling and provide useful suggestions for large-size operations of a freight transport service.

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Keywords: Ant Colony Optimization; Vehicle Routing Problem; Multi-agent simulation, Logistics.

I. Research contribution

The transport of goods often represents the main cost item for a logistic company. By improving route assignments to the vehicles of the fleet, it is possible to obtain significant time and cost savings. A huge amount of scientific literature has been produced with the aim of optimizing delivery and/or pickup operations for a fleet of vehicles serving a set of customers and subject to side constraints. Different variants of Vehicle Routing Problems (VRPs) exist, in which a fleet of vehicles must be optimally routed from one (or more) depot(s) to supply a set of geographically dispersed customers with known demand. Since we deal with NP-hard problems, a feasible way to tackle them is to design heuristic algorithms able to generate solutions that are as close as possible to the optimal one. Among them, Ant Colony Optimization (ACO) algorithms (Dorigo and Stützle, 2004) are conceived to find the minimum cost paths within a network, so it presents several applications to routing and scheduling problems and is of particular interest in transport problems (Zhang et al., 2008; Neogi et al., 2018; Calabrò et al., 2020). The excellent performances of ACO in solving such optimization problems are highlighted by the works of Catay (2009) and Carabetti et al (2010), which successfully applied the ACO approach to a series of benchmark problems. This work proposes a solution methodology for the Vehicle Routing Problem with Simultaneous Pickups and Deliveries and Maximum Travel Time (VRPSPD-MT). We use an improved ACO algorithm to solve large-scale routing problems involving a single depot, as origin and destination of an homogeneous (in terms of capacity) fleet of vehicles, the simultaneous pickups and deliveries of the goods from/to different customers, under the restrictions of maximum capacity and travel time. Since the model can be easily applied to real transport networks, allowing to vary and verify the incidence on the cost outputs of different simulation’s parameters which can characterize specific situations, also providing decision support to operators and companies in the management and optimization of their logistics operations.

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2. Methodology

The physical components of the VRPSPD-MT optimization model are: (1) the set of vertices $A = C \cup \{dep\}$, where $C = \{1, 2, ..., n\}$ is the set of clients spread on the study area, each one characterized by geographical coordinates, unique ID number, a pick-up demand $p_i$ and/or a delivery demand $d_i$ of palletized goods, while $dep$ is the depot, namely the origin or destination of goods; (2) the road network and the set of possible edges $i, j \in L$ between client nodes, with a related travel distance $r_{ij}$; (3) a fleet of vehicles $V$, with the same capacity $Q$, carrying a (variable) load $q_i$ moving between clients. We fix the maximum travel time $T$ for each vehicle (work hours constraint), we consider an additional service time $\tau_s$ due to the loading and unloading operations and we ignore the congestion on the road network (suburban context), thus assuming the speed for vehicles to be proportional to the road distance of the crossed edge. The objective function $Z$ to minimizes includes the weighted sum of number of vehicles and distance travelled: 

$$
\min(Z = \sum_{e \in E_v} e_v + \sum_{k \in E_v} \sum_{i \in A} \sum_{j \in A} e_{km} \cdot r_{ij} \cdot x_{ij}),
$$

given the decision variable $x_{ij}$ (equal to 1 if vehicle $k$ use the edge $ij$ and equal to 0 otherwise), considering the cost of using a vehicle in the work day and the cost related to the distance travelled, while taking into account (a) a work hours constraint: $\sum_{i \in A} \sum_{j \in A} (r_{ij} / v_{ij} + \tau_j) \cdot x_{ij} \leq T$, $\forall k \in V$; (b) the indivisibility of load demand: $\sum_{k \in E_v} \sum_{i \in A} x_{ijk} = 1$, $\forall j \in C$; (c) the vehicle capacity constraint: $0 \leq q_{ij} \leq Q$, $\forall i, j \in A, \forall k \in V$. The optimal assignment of vehicles to routes is achieved by using an ACO algorithm (it is not described in detail for the sake of brevity) derived from the MAX-MIN Ant System (Stützle and Hoos, 2000). The “random proportional rule” that ants use to move from customer $i$ to customer $j$ takes into account the pheromone trail $\tau_{ij}$, representing the experience of the ants in the exploration of good solutions, and an improved heuristic function $\eta_{ij}$, which considers both the distance (static cost) and the residual loading capacity (dynamic component) of the vehicle. Simulations have been carried out in the NetLogo multi-agent programming and modelling environment (Wilensky, 1999).

3. Results and discussion

The described methodology is applied to the area of Catania (Italy) where a sample of 120 clients has been identified. Pickup $p_i$ and delivery $d_i$ demand have been randomly generated with a Poisson distribution, and several simulations have been performed considering 5 different steps of overall demand, with gradually increase from a minimum of 120 load units to a maximum of 1500 units. It is observed that the total cost and the travelled distance for load units tend to decrease as the total demand increases. This trend is more noticeable for lower demand values, because the number of vehicles has a greater impact on the cost function. In fact, when the overall demand is low and scattered, the vehicles achieve low load factors (< 0.6), while for higher demand values a more efficient schedule of the fleet can be carried out and clusters of neighbouring clients can be easily served by the same vehicle. Such improvements however tended to stabilize beyond certain levels of demand (500-800 units). The proposed model can support the logistics operators during the route planning phase, optimizing the operations related to their service. Therefore, this study lays the basis for a deeper analysis in order to investigate the logistics process in its overall perspective and paves the way for a well-thought-out decision support service of an optimized logistics freight transport.

Main references


