

1. HFMD CVRP formulation

1.1. Introduction

This formulation is for a HFMD CVRP (Heterogeneous Fleet Multi Depot Capacitated Vehicle Routing Problem) where the fleet is composed by different vehicles and more than one depot can dispatch the vehicles. The objective is simple: assign a route and a depot to every vehicle to attend the demand of all the clients.

1.2. Sets

The HFMD CVRP is designed upon a connected and directed Graph $G = (N, A)$. The set of nodes N is composed by a set of clients C and a set of depots D ($N = C \cup D$). The set of arcs is represented by A . The set K corresponds to the set of available vehicles to attend the demand. As the fleet is supposed to be heterogeneous, the capacity of each vehicle k is given by q_k . The cost of using the arc (i, j) is represented with c_{ij}^k for vehicle k . The demand of every client is dem_c . Lastly, as the depots have a finite capacity to attend the vehicles, a maximum depot capacity R_d is added to each depot d (this capacity is given in terms of the demand the depot can attend).

1.3. Variables

It uses the following sets of variables:

- $x_{ij}^k \in \{0, 1\}$: binary variable which takes the value 1 if the arc (i, j) is used by the k^{th} vehicle, and zero otherwise. The number of variables of this family is $|K| \cdot |N^2|$.

- $f_{ij}^k \geq 0$: continuous auxiliary variable which represents the demand already attended when vehicle k use arc (i, j) . The objective of this variable is to ensure that the routes of each vehicle are well-defined and avoid cycling. It is also important to evaluate the capacity of the depots. The number of variables of this family is $|K| \cdot |N^2|$.
- $w_d^k \in \{0, 1\}$: Binary variable which takes the value 1 if vehicle k is served from depot d and zero otherwise. The number of variables of this family is $|K| \cdot |D|$.
- $z_c^k \in \{0, 1\}$: Binary variable which takes the value 1 if vehicle k serves client c and zero otherwise. The number of variables of this family is $|K| \cdot |C|$.

1.4. Formulation

$$(\text{HFMD CVRP}) \min \quad Z = \sum_{k \in K} \sum_{i \in N} \sum_{j \in N} c_{ij}^k \cdot x_{ij}^k \quad (1)$$

$$\text{subject to} \quad \sum_{k \in K} z_c^k = 1 \quad \forall c \in C \quad (2)$$

$$\sum_{c \in C} \text{dem}_c \cdot z_c^k \leq q_k \quad \forall k \in K \quad (3)$$

$$\sum_{j \in N} x_{dj}^k = w_d^k \quad \forall d \in D, k \in K \quad (4)$$

$$\sum_{i \in N} x_{id}^k = w_d^k \quad \forall d \in D, k \in K \quad (5)$$

$$\sum_{d \in D} w_d^k \leq 1 \quad \forall k \in K \quad (6)$$

$$\sum_{i \in N} x_{ic}^k - \sum_{j \in N} x_{cj}^k = 0 \quad \forall c \in C, k \in K \quad (7)$$

$$\sum_{d \in D} \sum_{c \in C} f_{dc}^k = 0 \quad \forall k \in K \quad (8)$$

$$\sum_{i \in N} f_{ic}^k - \sum_{j \in N} f_{cj}^k + \text{dem}_c \cdot z_c^k = 0 \quad \forall c \in C, k \in K \quad (9)$$

$$\sum_{i \in N} \sum_{k \in K} f_{id}^k \leq R_d \quad \forall d \in D \quad (10)$$

$$w_d^k \in \{0, 1\} \quad \forall d \in D, k \in K \quad (11)$$

$$x_{ij}^k \in \{0, 1\} \quad \forall i, j \in N, k \in K \quad (12)$$

$$0 \leq f_{ij}^k \leq q_k \cdot x_{ij}^k \quad \forall i, j \in N, k \in K \quad (13)$$

$$z_c^k \in \{0, 1\} \quad \forall c \in C, k \in K \quad (14)$$

Constraints (2) ensure that every client is visited at least once. Inequal-

ities (3) limit the amount of clients served by a vehicle according to their capacity. Constraints (4) and (5) guarantee that the vehicles depart and finish the route at the depot assigned to them. Inequality (6) only allows vehicles to be attended from one depot. Equalities (7) assure that the flow continues through the network. Equation (8) determines that all the initial arcs have not attended any demand. Equations (9) adds the demand attended in every client to the next arc used. Inequalities (10) guarantee that the capacity of every depot is not exceeded. The last four expressions define the domain of the decision variables.