Bicycle Network Improvements

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Mots-clés : *recherche opérationnelle, optimisation, réseau cyclable.*

1 Introduction

After having proposed methods to compute secure paths dedicated to bicycle in order to improve safety for bike users [1], we are interested here in the improvement of the cycle network in order to increase the overall safety of the users. While the development of mobility with low GHG emissions is an essential issue for all cities, it now appears necessary to intelligently deploy bicycle facilities to strengthen users' feelings of safety [2, 3, 4]. The problem we are addressing here consists in using a set of GPS tracks corresponding to paths taken by cyclists, to propose improvements to the cycle network, eg. installation of cycle lanes on one or more sections, in order to increase the overall safety of users, respecting a given budget.

2 Model

Given a graph describing the network, costs representing the distance and the unsafety of the roads with and without improvements, a set of origin/destination (OD) pairs, and for each OD pair a user preference between distance and unsafety, the model computes both the path of each OD pair and the roads to improve within a given budget. Here we consider that the cost of an improvement is proportional to the distance of the arc that is modified.

Parameters : The road network is represented by an oriented graph $G(X, A)$ with X ($|X| = n$) the set of nodes, and A the set of arcs. Each arc is associated with four costs : c^1_{ij} (resp. $\overline{c_{ij}}^1$) is the distance cost of arc (i, j) before (resp. after) improvements, and c^2_{ij} (resp. $\overline{c_{ij}}^2$) is the unsafety cost of arc (i, j) before (resp. after) improvements. We are also given a set P ($|P| = s$) of origin/destination pairs, also called paths in what follows. Each path $k \in 1, .., s$ has a departure node $start_k \in X$, a destination node $end_k \in X$, and a weight $\alpha_k \in [0..1]$ representing the preference of the user in terms of distance versus unsafety. Lastly, function $succ(i)$ returns the successors of node i in graph G, and $pred(i)$ returns the predecessors of node i in graph G.

Variables : The main decision variables are the variables $\overline{\sigma_{ij}}$, which is equal to 1 if arc (i, j) is modified, 0 otherwise. When this variable is equal to one, (i, j) must be modified for all paths going through it. Then, we have variables to model the routing of bikers : δ^k_{ij} is equal to 1 if arc (i, j) is in path k (modified or not). Finally, to compute the cost of each path, we need the two following variables :

— y^k_{ij} : $y^k_{ij} = 1$ if arc $(i, j) \in A$ is part of the path k and the arc (i, j) is not modified, 0 otherwise.

— $\overline{y_{ij}}^k$: $\overline{y_{ij}}^k = 1$ if arc $(i, j) \in A$ is part of the path k and the arc (i, j) is modified, 0 otherwise.

$$Minimize \sum_{k\in P} C_k \tag{1}$$

$$y_{ij}^k + \overline{y_{ij}}^k \leq 1, \forall k \in P, \forall (i,j) \in A \tag{2}$$

$$\overline{\sigma_{ij}} \geq \overline{y_{ij}}^k, \forall k \in P, \forall (i,j) \in A \text{ and } 1 - \overline{\sigma_{ij}} \geq y_{ij}^k, \forall k \in P, \forall (i,j) \in A \tag{3}$$

$$\delta_{ij}^k = y_{ij}^k + \overline{y_{ij}}^k, \forall (i,j) \in A, \forall k \in P, \tag{4}$$

$$\sum_{j\in succ(start_k)} \delta_{start_k,j}^k = 1, \forall k \in P, \text{ and } \sum_{j\in pred(end_k)} \delta_{j,end_k}^k = 1, \forall k \in P, \tag{5}$$

$$\sum_{i\in pred(j)} \delta_{i,j}^k = \sum_{l\in succ(j)} \delta_{j,l}^k, \forall k \in P, \forall j \in N \backslash \{start_k, end_k\} \tag{6}$$

$$\sum_{i\in pred(j)} \delta_{i,j}^k \leq 1, \forall k \in P, \forall j \in N \text{ and } \sum_{l\in succ(j)} \delta_{j,l}^k \leq 1, \forall k \in P, \forall j \in N \tag{7}$$

$$\sum_{(i,j)\in A} \overline{\sigma_{ij}} c_{ij}^1 \leq B \tag{8}$$

$$C_k = \sum_{(i,j)\in A} y_{ij}^k [(c_{ij}^1 \alpha_k) + (c_{ij}^2 (1-\alpha_k))] + \sum_{(i,j)\in A} \overline{y_{ij}}^k [(\overline{c_{ij}}^1 \alpha_k) + (\overline{c_{ij}}^2 (1-\alpha_k))] \tag{9}$$

(2) and (3) ensure consistency of y and $\overline{y}$ variables. These constraints ensure that if an arc is modified, it is modified for all paths passing by this arc. Alternatively, if an arc is not modified, it is not modified in other paths. Notice that (2) is not mandatory due to (3) formulation. (4) to (7) guarantee the consistency of the calculated paths between each OD pairs. (8) limit the total length of modified arcs with an upper bound B. (9) represent the cost of a path : for each path k, its cost takes into consideration whether the arcs are modified or not, as well as the user preference between distance and unsafety via the parameter α_k. Finally, the objective function 1 minimizes the sum of the costs of all the paths.

3 Conclusions and perspectives

Other extensions will also be considered, e.g., promoting the improvement of sections connected to each other in order to offer complete cycle routes, the explicit consideration of user paths to ensure that the proposed solutions are not too different, etc. First results on small graphs, and real size graphs will illustrate the presentation and show the limits of the model.

Références

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