18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015,
Delft, The Netherlands

Designing single origin-destination itineraries for several classes of cycle-tourists

Federico Malucelli [a], Alessandro Giovannini [b], Maddalena Nonato [c,*]

[a]*Dipartimento di Elettronica Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci 32, Milano 20133, Italy*
[b]*Dipartimento di Matematica, Universitá degli Studi di Milano, via Saldini 50, Milano 20133, Italy*
[c]*Dipartimento di Ingegneria, Universitá degli Studi di Ferrara, via G. Saragat 1, Ferrara 44122, Italy*

Abstract

This study concerns the optimal design of cycle tourist itineraries considering several classes of users. It builds upon a recent work which first introduced the problem of designing the most attractive itinerary for cycle tourists connecting a given origin to a given destination, subject to a budget and a time constraint. Starting from a network made of existing cycle-trails, gravel paths, and unsurfaced field roads, local administrators face the problem of selecting a budget-compliant set of edges to be reconditioned and turned into paved bike trails. Indeed, investing in enhancing cycle tourism infrastructures proved to be effective in fostering sustainable development but decision support tools are needed to support decision makers in optimizing scarce public resources spending. The key issue in this problem is the objective function, namely the route attractiveness. Each node and each edge of the network yields a reward each time it is traversed, related to the pleasure of cycling along it. Additional pleasure usually decreases when traversing the same edge or node one more time but it may still be positive. Therefore, the optimal route may contain cycles, which is a special feature of this problem. In previous studies attractiveness was computed on the basis of each point of interest located on the edges and at the nodes of the route, and the route maximizing total attractiveness was searched for. The focus was on the *generalist cycle tourist*, without thematic preferences. This study takes a more realistic view and proposes a model where different classes of cycle tourist are considered individually, each one with its own preferences, like the cultural oriented tourist, the gastronomic fan, or the one fond of wild life and nature. This new perspective yields a new network design problem in the field of vehicle routing problems with profits, generalizing the Orienteering Problem, that we call the *multi-commodity orienteering problem with network design* (MOP-ND): it consists of designing a set of itineraries, one for each user class, sharing the same origin and the same destination and potentially any edge of the network, so that each itinerary satisfies a maximum duration constraint and the cost of the whole infrastructure is budget compliant. The objective is to maximize the sum on all user classes of the attractiveness of the itinerary selected for that class. In this paper we provide a mathematical model for MOP-ND, test it on realistic data, and compare with the generalist model.

---

* Corresponding author. Tel.: +39-0532-97-4994 ; fax: +39-0532-97-4870.
  E-mail address: nntmdl@unife.it

1. Problem description

Cycle tourism is emerging as a sustainable strategy for promoting economic growth, able to redistribute to an entire region the incomes due to increased tourist flows. Visitors spend money into lodging, food, and local handicrafts, in addition to all services related to a holiday by bike such as technical assistance, luggage transportation, and guided tours. These are small scale business ventures that do not need big capital investments and may encourage young people not to leave their home in the countryside and contribute to local development. However, the governmental role is fundamental. As discussed in Cox (2012) where Belgium and the Netherlands are compared, local governments policies strongly influence the development of a cycle friendly attitude, affecting also the popularity of the bicycle as a mean of transport. Once a region enjoys few features that make it worth the visit, such as a strong cultural identity, a territory marked by historical sites, plus pleasant weather and beautiful nature, if it is well connected to the transportation network only the lack of adequate biking tracks impasses the development of local and international cycle-tourism. Indeed, cycle tourists don't look for big expensive facilities while they tend to appreciate unspoilt surroundings and getting in touch with local people according to a slow motion way of traveling. There is one feature, though, to which cycle tourists are sensitive, that is safety on the road. For this reason the best way to spur this business is to set up a network of dedicated tracks where bicycles are the only mean of transport allowed.

In this paper we focus on the Trebon region in South Boemia, Czech Republic, whose local administrators face the problem of wisely investing scarce public resources for the purpose of setting up a cycle-tourist network by re-conditioning existing tracks or building brand new ones in a sustainable manner. Potential tracks include field and forest roads, gravel roads, dismissed rail tracks, as well as, in our case study, abandoned army trails. Decision support systems based on quantitative methods are necessary to provide decision makers with the best tools to make the right choices according to optimization criteria, so that the resulting network provides accessibility to the most attractive locations and allows several different itineraries able to meet distinct cycle-tourist expectations. Indeed, the application of optimization techniques to the field of recreational systems is flourishing (Shcherbina and Shembeleva (2014)), the most representative case being given by the many applications of the Orienteering Problem (OP) and its several variants in the family of routing problems with profits for the sake of tourist route planning (Vansteenwegen et al. (2011)). The majority of studies concerning the optimized planning of touristic itineraries concentrate on target selection and on the routing (Gavalas et al. (2014)), assuming that the infrastructure is given: for example Vansteenwegen and Van Oudheusden (2007) studies the problem of supporting the tourist in selecting his/her own preferred itinerary according to individual preferences, taking for granted that the tourist exploits the existing transit network to move around the city, while (Liang et al. (2013)) does not contemplate any infrastructure since activities take place outdoor. On the opposite, our focus is on the design of the network infrastructure, guided by the potential use that cycle tourists will make of the resulting network. While disregarded in the tourism framework, the topic of bicycle network design has been intensively tackled by transportation engineers looking for effective planning strategies to promote the use of bicycle as a mean of transport. Commonalities and differences can be highlighted between the methodologies adopted when planning leisure oriented or transportation oriented bicycle infrastructures.

In both cases, how to model the user preferences that guide the cyclist route choice is a challenging problem. Bicycle as a mean of transport is a central issue in sustainable transportation planning, and public agencies tend to invest in improving bicycle devoted infrastructures in order to induce modal shift from private car to multi-modal transportation systems made of a mix of public transit, bicycle, and walking, to reduce traffic congestion, curtail auto emissions in urban areas, and improve life quality and health conditions by physical activity Rybarczyk and Wu (2010). To meet these goals cycling in town must be safe and desirable, but how to make people actually change their habits and switch from car to bicycle is still highly debated. In fact, cyclist behavior and preferences have not so far been fully understood so to formulate consistent mode choice and route choice models and come up with reliable bicycle travel demand data associated with potential infrastructure improvements, able to forecast the impact of different measures aimed at promoting cycling. Supply-based models tend to evaluate infrastructures by quality indexes such as bicycle level of service (BLOS) or bicycle compatibility index (BCI) that address the safety of itineraries and how comfortable the roadway is, but several studies on risk perception show the limits of such measures and the need for more sophisticated tools to assess perceived risk Parkin et al. (2007). Indeed, increasing BLOS or BCI alone or reducing perceived risk will not necessarily induce bicycle traffic. A recent study in Wardman et al. (2007) showed that economic reward would play as much a role as a devoted segregated cycleway in making people cycling to work. Moreover, cultural

differences exist among European countries as well as among large cities and country side residents and play a role in the attitude towards cycling, see Heinen et al. (2011), therefore demand-based models should integrate them to provide trustworthy travel demand forecasts.

In both settings, i.e. leisure and commuting, travel duration must be limited. When commuting, several studies such as Furth and Noursalehi (2015) suggest that itineraries not longer that 10% of the shortest path from origin to destination are considered as viable alternatives, as far as safety is guaranteed. When cycling for leisure, different classes of users should be considered, each one with its own time limit, ranging from few to several hours.

Another common aspect is the need for a system wise approach, considering the interaction of the new infrastructure with existing facilities and how users may potentially react to changes. In our project, whose final aim is to design the whole cycle tourist network, it means to consider the entire set of attractions present in the area, the existing tracks, the most likely set of origin-destination pairs, and different user classes, attacking the problem from the demand side as well as from the side of the supply. Likewise, Duthie and Unnikrishnan (2014) describes the challenges of designing a network of bicycle facilities in the downtown Austin region, minimizing the cost required to upgrade up to a minimum quality a set of roadways and intersections necessary to connect several origin-destination pairs along itineraries with a maximum delay with respect to the shortest path. A similar study is Smith and Hagani (2012), where a MILP model for a multi commodity flow with fixed charge network design is proposed and solved by a state of the art solver for small size instances, to incorporate bike related facilities into an existing urban road network in a cost effective manner, minimizing the weighted sum of path duration and (the complement to) level of service, emphasizing that a local improvement on an edge impacts on all the itineraries traversing that edge. The authors conclude that realistic instances can not be solved by state of the art MILP solvers and suggest to develop ad-hoc heuristics.

In summary, it appears that there is no standard way to design bicycle routes at a network level. We share the same concern with respect to our problem and we try to contribute to fill this gap in the field of cycle tourism: we believe that an efficient solution approach for the single o/d multi commodity problem, such as the one here proposed, may provide a building block for heuristic, decomposition-based, solution approaches for the network design problem.

The present study builds upon a recent work which first introduced the problem of designing the most attractive, bike devoted, itinerary connecting a given origin to a given destination, subject to a budget and a time constraint: given a set of either existing or potential cycle-trails, a budget-compliant set of edges had to be selected in order to be reconditioned and turned into a paved bike trail able to meet bikers expectations. The key issue in this problem is the objective function, namely the route attractiveness, based on the reward provided by traversing the nodes and the edges a route is made of. In previous studies attractiveness was computed on the basis of the attractions located on the edges and at the nodes of the route, and the route maximizing total attractiveness was searched for. The focus was on what we call the *generalist cycle tourist*, meaning a tourist who accumulates the rewards related to each attraction encountered along the way, with no thematic preferences. This study takes a more realistic view and proposes a model where different classes of cycle tourist are considered individually, each one with its own preferences, so that the same itinerary provides a different reward depending on the user class. We consider the problem of designing a set of itineraries with a common origin and a common destination, each addressing the preferences of a particular class of cycle tourists. Each class focuses on a particular class of attractions. Here we suggest three different user profiles, namely cultural, gastronomic, and naturalistic, however, any other set of profiles can be considered without loss of generality. The naturalistic user is attracted by observation decks, waterfalls, and likes to ride paths on scenic landscapes or along a lake best if equipped with bathing facilities. The cultural profile privileges museums and galleries, historical monuments, buildings, and temples. The gastronomic oriented cycle tourist searches for food markets, wineries, restaurants, or places where typical food is produced and sold.

Selecting the most suitable quantitative method for measuring the attractiveness of an itinerary is not straightforward. We stick with a well assessed methodology adopted in Cernà et al. (2014), which enables us to compare with a benchmark. While the methodology for data collection is not dealt with in this paper, for sake of completeness we provide a short description. The first step concerns the identification of the potential classes of points of interests (PoIs). First, a data mining process on the Internet web sites related to cycle tourism has been carried out to collect and evaluate natural, cultural, and service facilities related PoIs. Then, local bike riders were interviewed to spot, list, and evaluate the PoIs in the Treborn Region through questionnaires marking and scoring PoIs for each location situated on the potential network links. Users were assumed to be identically competent and informed. For each PoI, bikers scores were averaged to compute the score of the PoI. In Cernà et al. (2014), the first visit attractiveness was

computed as the sum of the scores of the individual PoIs present at a location or along a link, respectively. When focusing on different classes of users, the attractiveness function for each user class can be computed adopting the above mentioned procedure, by disregarding those scores due to PoIs belonging to categories not contemplated within the user interests. From the above discussion it follows that multiple traversals may increase total reward. So, a bound on the total duration of the itinerary not only models the real behavior of cycle tourists but also ensures that the optimization problem is well posed and has a finite solution even if the marginal attractiveness of some location never becomes negative.Moreover, modeling how reward changes at successive traversals is necessary for a realistic problem description. Therefore, the graph based mathematical model must handle both non elementary paths and non linear objective functions. The paper is organized as follows: in Section 2 a mathematical formulation of the problem is provided, and differences and commonalities with related problems are analyzed. In Section 3 the experimental campaign on the Trebon region data is described, conclusions are drawn and future work is sketched in Section 4.

2. A MILP model

From a mathematical point of view, the problem can be modeled as a constrained multi-commodity flow with network design, where each commodity represents a user profile who collects only the prizes associated to its own profile while traversing edges and nodes. We discuss how to model the objective function by generalizing the attractiveness function proposed in Cernà et al. (2014), and introduce an ILP model underlining common features with the family of the Orienteering Problem (OP) and the Multicommodity Minimum Cost Flow with Network Design Problem. As in Cernà et al. (2014), we deal with two-ways, bike-devoted tracks. The network of potential bike tracks is represented as a mixed graph $G = (N, A \cup E)$ where N models the set of intersections and E models the set of tracks connecting two adjacent intersections $i, j \in N$, $i < j$, while each arc in $A = \{(i, j), (j, i) \; \forall \, [i, j] \in E\}$ represents the action of traversing edge $[i, j]$ from i to j or vice-versa. For each arc, traveling time $t_{ij} > 0$ is known and it depends on the track length as well as on the slope from i to j. The total travel time of an itinerary can not exceed a threshold T. The reconditioning of edge $[i, j]$ costs $c_{ij} \geq 0$ and the budget for the entire infrastructure is B. On this graph, n_u (not necessarily elementary) paths from a given origin $s \in N$ to a given destination $t \in N$ are sought, one for each class of users $u \in U = \{1..,n_u\}$. Attractiveness is defined on edges and nodes. It depends on the user class and not on the direction of traversal. Let $\{\varphi_u^i(.), i \in N\}$ and $\{\phi_u^{ij}(.), [i, j] \in E\}$ denote the family of utility functions for user class $u \in U$. For each user u we assume the following: i) no traversal yields null reward, so that $\varphi_u^i(0) = \phi_u^{ij}(0) = 0$ $i \in N, [i, j] \in E$; ii) the reward at first traversal for each node and edge is given; it is denoted as $\varphi_u^i(1) \; \forall i \in N$ and $\phi_u^{ij}(1) \; \forall [i, j] \in E$, which equals marginal attractiveness at first traversal, due to i); iii) given $\bar{k}$ the maximum number of traversals admitted (usually ≤ 3), and $K = \{0, 1..\bar{k}\}$ the associated index set, for each traversal $k \in K$, marginal reward is $\beta_i^{ku} = \varphi_u^i(k) - \varphi_u^i(k-1)$ for node i and $\alpha_{ij}^{ku} = \phi_u^{ij}(k) - \phi_u^{ij}(k-1)$ for edge $[i, j]$. Since attractiveness is not linear, we exploit marginal attractiveness to formalize it as the objective function of an ILP model. Variables represent flow and design decisions. Design is modeled by a family of boolean variables z_{ij} for each edge $[i, j] \in E$,which describe the connected subnetwork made of all the edges that belong to any selected itinerary. Flow is multi-commodity, to represent the different classes of users. For each such class, integer flow variables describe the itinerary from s to t on the infrastructure induced by the design variables z_{ij} and are also used to model the maximum duration constraint. In particular, for each arc $(i, j) \in A$ and for each user $u \in U$, variables x_{ij}^u represent the number of times user u traverses the arc from i to j along the way from s to t. It follows that the amount of u-flow (flow of commodity u) on edge $[i, j]$ is given by $x_{ij}^u + x_{ji}^u$, while the amount of u-flow through node i is $\sum_{ij \in FS(i)} x_{ij}^u$, i.e., the sum of the flow on the arcs of the forward star $FS(i)$.

Let us introduce $\bar{k}$ boolean variables χ_{ij}^{ku} for each edge, user, and $k = 1, .., \bar{k}$, such that $\chi_{ij}^{ku} = 1$ *iff* on edge $[i, j]$ there are at least k units of u-flow, i.e., $x_{ij}^u + x_{ji}^u \geq k$. Likewise, the boolean variable $\gamma_i^{ku} = 1$ *iff* at least k units of u-flow traverse node i. Variables χ and γ are introduced in order i) to model the objective function and ii) to enforce the value of design variables. In fact, i) $\phi_u^{ij}(x_{ij}^u + x_{ji}^u) = \sum_{k=1}^{\bar{k}}(\alpha_{ij}^{ku}\chi_{ij}^{ku})$ and $\varphi_u^i(\sum_{ij \in FS(i)} x_{ij}^u) = \sum_{k=1}^{\bar{k}}(\beta_i^{ku}\gamma_i^{ku})$; ii) z_{ij} is equal to 1 as soon as there is flow from i to j or vice-versa, whatever the user, i.e. $z_{ij} = max_u \{\chi_{ij}^{1u}\}$.

The following ILP model provides a mathematical formulation.

$$P : \max \sum_{u \in U} \sum_{k=1}^{\bar{k}} \left(\sum_{(i,j) \in A} a_{ij}^{ku}\chi_{ij}^{ku} + \sum_{i \in N} d_i^{ku}\gamma_i^{ku} \right) \quad \text{subject to:} \tag{1}$$

$$\sum_{(i,j)\in FS(i)} x_{ij}^u - \sum_{(h,i)\in BS(i)} x_{hi}^u = b_i \qquad\qquad \forall i \in N, \forall u \in U \tag{2}$$

$$\sum_{(i,j)\in A} t_{ij} x_{ij}^u \le T \qquad\qquad \forall u \in U \tag{3}$$

$$x_{ij}^u + x_{ji}^u = \sum_{k\in K} \chi_{ij}^{ku} \qquad\qquad \forall [i,j] \in E, \forall u \in U \tag{4}$$

$$\chi_{ij}^{ku} \le \chi_{ij}^{k-1,u} \qquad\qquad \forall [i,j] \in E, \forall u \in U, k = 2, \ldots, \bar{k} \tag{5}$$

$$z_{ij} \ge \chi_{ij}^{1u} \qquad\qquad \forall [i,j] \in E, \forall u \in U \tag{6}$$

$$\sum_{(i,j)\in A:i<j} c_{ij} z_{ij} \le B \tag{7}$$

$$\sum_{(h,i)\in BS(i)} x_{hi}^u = \sum_{k\in K} \gamma_i^{ku} \qquad\qquad \forall i \in N, i \ne s, \forall u \in U \tag{8}$$

$$\sum_{(s,i)\in FS(s)} x_{si}^u = \sum_{k\in K} \gamma_s^{ku} \qquad\qquad \forall u \in U \tag{9}$$

$$\gamma_i^{ku} \le \gamma_i^{k-1,u} \qquad\qquad \forall i \in N, \forall k \in K, \forall u \in U \tag{10}$$

$$\gamma_i^{1u} \ge \sum_{[i,j]\in E:i\in N^{st}, j\notin N^{st}} \chi_{ij}^{1u} \qquad\qquad \forall v \in N^{st}, \forall N^{st} \subseteq N, \forall u \in U \tag{11}$$

$$z_{ij} \in \{0,1\} \qquad\qquad \forall [i,j] \in E \tag{12}$$

$$x_{ij}^u \in Z^+ \qquad\qquad \forall (i,j) \in A, \forall u \in U \tag{13}$$

$$\chi_{ij}^{ku} \in \{0,1\} \qquad\qquad \forall [i,j] \in E, \forall k \in K, \forall u \in U \tag{14}$$

$$\gamma_i^{ku} \in \{0,1\} \qquad\qquad \forall i \in N, \forall k \in K, \forall u \in U \tag{15}$$

The objective function (1) is the maximization of the marginal attractiveness collected by each user at each edge and node along the chosen itinerary at each kth traversal. Eq.s (2) are flow balance constraints, where $FS(i)$ and $BS(i)$ denote the forward and the backward star of node i, while b_i is -1 for $i = s$, $+1$ for $i = t$, and 0 otherwise. Eq.s (3) impose a maximum traveling time for each itinerary. Eq.s (4) introduce the family of χ variables, while eq.s (5) ensure that an edge can not be traversed k times if it has not been traversed $k-1$ times. Eq.s (6) introduce z_{ij} as $max_{u\in U}\{\chi_{ij}^{1u}\}$. Eq.s (7) bounds the infrastructure cost. This is the only constraint which ties together the decisions involving the different users. Connectivity is enforced for each u-flow by eq.s (11), a potentially exponential number of constraints which require a positive u-flow in each cut $N^{st}, N \setminus N^{st}$, where N^{st} denotes any subset of nodes including s and t, whenever a node in $N \setminus N^{st}$ is selected as part of the itinerary of user u from s to t. Constraints (12-15) bind variables to be binary or integer.

This problem, which to the best of our knowledge has never been studied, shares features from two well known combinatorial optimization problems: the Orienteering Problem (OP), where a maximum distance constrained tour is sought such that it maximizes the sum of the prizes associated to the visited nodes (see Fischetti et al. (2007) for a polyhedral study an refer to Vansteenwegen et al. (2011) for a recent survey on solution approaches), as well as the Multi-commodity Flow Network Design Problem. Therefore we call our problem the Multi-commodity Orienteering Problem with Network Design (MOP-ND).

3. Computational experiments

Computational results refer to real data related to the Trebon region, located close to the Austrian border in the South Bohemia province of the Czech Republic, whose local administrators face the problem of designing a network of tracks devoted to cycle tourism in order to support local economy development. The same set of data was used for developing and testing the single user case, in Cernà et al. (2014), so that we can compare against a benchmark. First we introduce the input data and then results are presented and discussed.

3.1. Problem data

The graph is made of a set of potential tracks, most of which require an investment to be reconditioned while few are already fitting and can be used at zero cost. The individual tracks, corresponding to graph edges, are either paved roads with low vehicular traffic, unpaved roads, or natural trails already being used for cycling or hiking. Their surface may be either asphalt, gravel, or they can be field/forest paths of bad quality, single-track (i.e. narrow, one-way) cycling paths which must be turned two-lanes wide, or concrete gravel path. The design cost depends on present condition and path length. Nodes are interesting points for tourists or cross-roads. The edge set was designed so that the main natural and cultural points of interest are reachable, for a total of 83 nodes and 147 edges. Arcs traveling time is computed with respect to an average speed of 18 km/h. on the flat, and adapted according to slope changes along the way, considering elevations and descents in each direction, so that travel time may differ in the two directions. The design cost of each edge is computed by multiplying the length (in meters) of the track to be reconditioned by the cost of paving for one meter. The estimated costs of a 3 meters wide path are: 115 € to turn it into an asphalt surface and 75 € for gravel one if starting from dirt road. Different scenarios arise depending on the kind of upgrading work to be done. In the MOP-ND attractiveness depends on the user class. We generated the data so that if all users choose the same itinerary, the total attractiveness equals the attractiveness of the generalist cyclist. As mentioned, first traversal attractiveness is based on the PoIs, at second and third traversal marginal attractiveness is one fourth of the previous one, and becomes null from the fourth traversal on. In the MOP-ND, the single-user first-traversal attractiveness was randomly split among the three classes. The cultural user has null reward from the second traversal onward, while at the second and at the third traversal the gastronomic and naturalistic user attractiveness share is computed according to the same proportion holding at first traversal.

3.2. Computational results

The ILP model introduced in Section 2 was coded in AMPL and solved by ILOG Cplex 12.5.0.0 on a quad core laptop with i7 processor. Connectivity constrains were dynamically introduced when violated, as follows. Iteratively, an integer solution is found and the set of nodes not connected to the origin-destination path is recorded. For each such node one connectivity cut described by eq.s (11) is added and the new ILP model is solved with a warm start. The origin destination pair is made of nodes $22 - 70$, which are located on the right and on the left of the region map, respectively, to recreate the same situations as in Cernà et al. (2014). Time units are minutes and distance is measured in kilometers. The shortest path from node 22 to node 70 takes 147 minutes while the cheapest path needs no investment, since it uses roads that are already paved. The nine scenarios differ regarding maximum duration T, considering the cases $T = 240$, $T = 330$ and $T = 420$ minutes, and budget, with cost upper bound B being 0, 1 million and 2 millions Euro, yielding a total of nine different scenarios, one per combination of T and B.

Table 1. Results for the 9 scenarios: maximum path duration T (minutes) and budget B (10^3 euros) for each scenario, number of iterations and total number of connectivity cuts added, Running times in seconds.

Scenario	T	B	It.	C.Cuts	Running time
1	240	0	4	17	2
2	240	1000	9	37	787
3	240	2000	10	34	276
4	330	0	3	2	23
5	330	1000	8	53	1002
6	330	2000	14	60	4863
7	420	0	4	32	3
8	420	1000	7	53	1519
9	420	2000	9	61	18

In Table 1 we report the description of the nine scenarios with respect to time and budget constraints and a summary of the solver performance with respect to the number of iterations: the total number of connectivity cuts added and the total running time in seconds to find the optimal solution for each scenario. The number of iterations ranges from 3 to 14 and the total number of added cuts ranges from 2 to 61 for the set of instances in our test bed. Running time
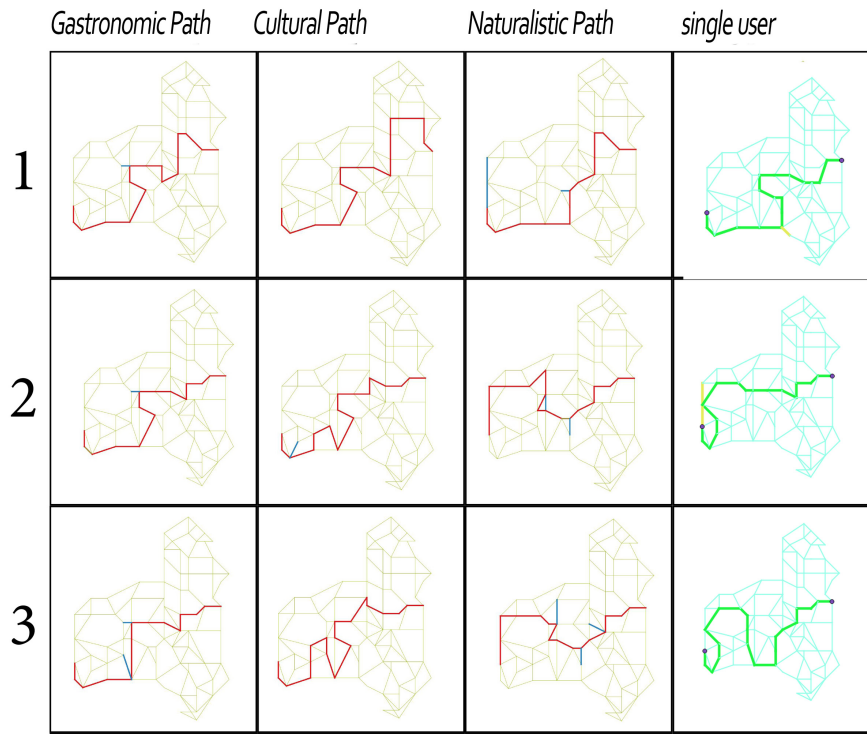
Figure 1. The first three scenarios: the most attractive itinerary for each user class compared to the generalist cycle tourist itinerary.

ranges from 2 seconds to 4.803 (1h, 20', 3"): while it increases with T and B, which influence the feasible region size, the trend is not monotonic and it seems to be also related to the number of iterations and generated cuts. With respect to single user case, MOP-ND takes longer, as expected, but still bearable for a design problem. Time increase is due to the larger number of variables and to the higher difficulty due to the linking constraint, i.e., budget is a limited resource that different users must share. The present running times are satisfactory since this design problem is solved off line. However, the performance of the dynamic cut generation procedure could be improved by keeping memory of previously generated cuts for previous scenarios. Another improvement may come from the integration of valid inequalities in the MOP-ND model, adapting those developed for the OP. However, this is not a trivial task since here the topological structure of the selected network may vary while in the OP it is always a tour. It can be observed that in the zero budget case running time is negligible, which comes at no surprise since the unique linking constraints is vanished, besides the fact that the set of available edges is limited. This feature could be exploited in a decomposition based solution approach for the network design problem, where, at each iteration, the set of edges to be reconditioned is set and each user class can make its best out of those edges, having the time limit as the unique constraint. For each of the 9 scenarios, Table 2 compares the total reward provided by the three user classes (third column) with the one obtained in Cernà et al. (2014) for the single user (fourth column), as well as the percentage of the available budget required by the infrastructure.

Results in Table 2 show that by exploiting the information regarding the different components making up the reward associated to an edge or a node, and allowing different classes of users to select their best itinerary, we get a set of itineraries that provide a consistent increase of total attractiveness. Indeed, the multi user case can be seen as a relaxation of the single user case, since the latter can be obtained by obliging all users to follow the same path. The fifth column in Table 2 reports the percentage increase of the total reward, which ranges from 11 to 26 percent. The higher degree of freedom in the present model impacts on the percentage use of the available budget: in the generalist case, for the lowest time limit $T = 240$ minutes no more than 80% of the available budget is exploited,
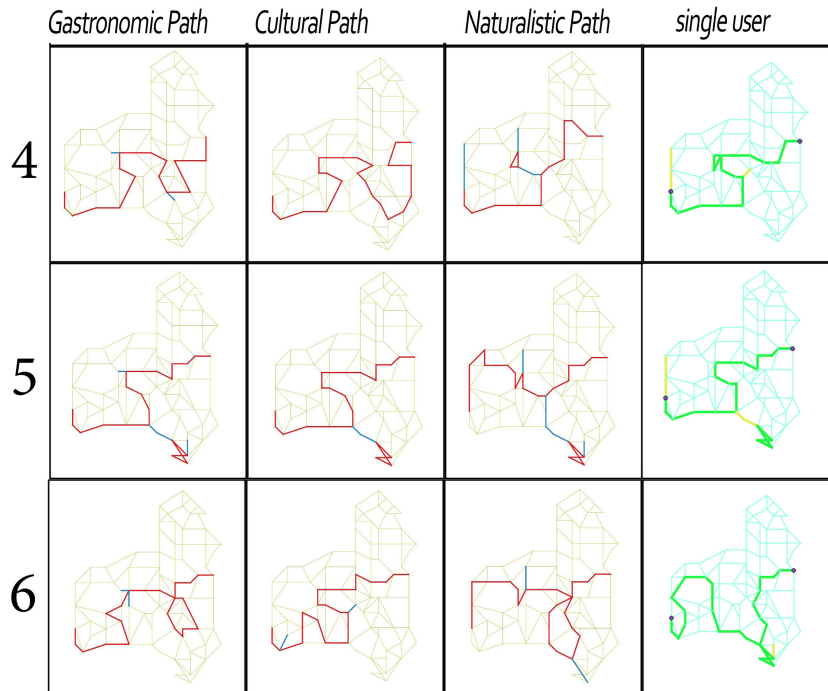
Figure 2. Scenarios 4, 5 and 6: the most attractive itinerary for each user class compared to the generalist cycle tourist itinerary.

Table 2. Rewards and percentage budget utilization multi-user case vs. single user, for the 9 scenarios.

Scenario	C/B%	Total reward	Reward single user	Variation%	single user C/B%
1	0	764	623	23	0
2	98.7	858	704	22	79.8
3	90.9	893	708	26	54.3
4	0	1012	863	17	0
5	98.5	1142	1006	14	50.9
6	98.1	1159	1037	12	91.4
7	0	1167	1049	11	0
8	96.3	1381	1243	11	74.2
9	98	1495	1309	14	90.2

which made sense since the shortest path from origin to destination required almost $3/5$ of T. In the multi user model case shown in Table 2, this percentage is always above 90% and often close to 100%. Table 3 reports for each individual class the duration of the path and the reward in each of the nine scenarios. Despite of the fact that attractiveness of cultural related PoIs goes to zero after the first visit, when time and budget allow to reach a larger set of PoIs reward increases substantially, taking advantage of the several noticeable attractions located in the region. For each user class and scenario, the available time is used almost completely, as it was the case for the single user: this is due to the possibility of getting additional reward beyond first traversal. As expected, reward increases whenever resource upper bound does, but the behavior differs for each user class. Indeed, the objective function maximizes total reward disregarding how this is shared among users. This practice makes sense from the decision maker point of view, since that particular area could be more gifted regarding certain features to the detriment of others, so that the attractiveness of one class of user could not increase without penalizing the others of a bigger amount. This
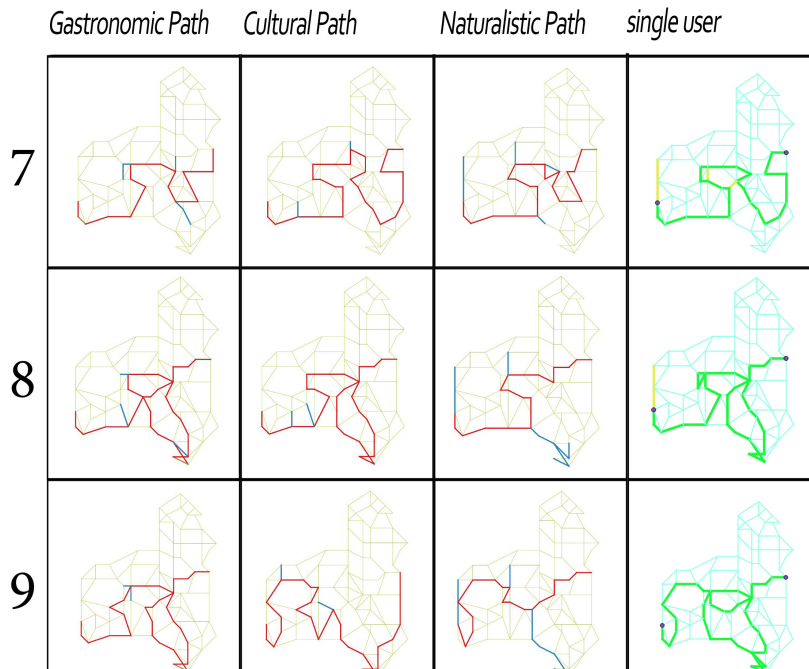
Figure 3. Scenarios 7,8, and 9: the most attractive itinerary for each user class compared to the generalist cycle tourist itinerary.

Table 3. For each scenario, the duration (T_1, T_2, and T_3) and the reward (R_1, R_2, and R_3) of the selected itinerary for the first, second, and third user class are reported.

Scenario	T_1	R_1	T_2	R_2	T_3	R_3
1	239	255	237	302	235	207
2	239	270	236	335	237	253
3	238	297	238	335	239	261
4	329	329	330	370	326	313
5	323	360	328	399	328	383
6	329	375	329	417	327	367
7	418	389	419	424	416	354
8	418	474	417	470	419	437
9	419	479	419	547	419	469

feature reflects the opportunity for planners to exploit the most the peculiarity of the area without enforcing fairness among users classes, and it can be considered a good practice as far as this specific tool is embedded into a more comprehensive methodology that aims at designing the whole network, where several origin destination pairs must be connected. At that network planning stage, fairness among the different users class can be handled as far as planners consider it a criterion to be satisfied in order to equally meet the preferences of the whole cycle tourist community, and thus enlarge the number of potential visitors. This issue will be dealt with in the future work, when tackling the design at the network level. Now we consider the topology of the itineraries. For each of the 9 scenarios, in particular scenarios 1, 2 and 3 in Figure 3.2, scenarios 4, 5 and 6 in Figure 3.2, and scenarios 7, 8 and 9 in Figure 3.2, respectively, the optimal itinerary for each users class is depicted, in the usual order (the gastronomic, the cultural, and the nature and sport fan). Edges traversed once are depicted in red, those traversed twice in blue and those traversed

three times in brown. In the fourth map, for each of the 9 scenarios, the most attractive itinerary of the generalist cycle tourist is shown, with single traversals depicted in green and edges traversed twice in yellow. As expected, the number of edges traversed twice decreases when budget increases, which can be related to the possibility of recondition a higher number of tracks. The possibility of diversifying the itinerary for each user class, even though the total budget is the same, allows for a considerable variety of routes, as it can be seen by comparing with the generalist case, and this is supported by a noticeable increase in total reward, as shown in Table 2. Recall that, for each edge and node, the attractiveness perceived by the generalist tourist has been split among the three user classes we consider here. Therefore, there is no gain due to the fact that three units of flow are now traversing the network from origin to destination instead of one, i.e., if the chosen itinerary of each class were the same as the generalist tourist itinerary, the total attractiveness would have been equal in both models.

4. Conclusions and final remarks

The main contributions of this paper are the following: i) we introduced the problem of designing the most attractive itineraries for a single origin-destination pair for different classes of users, each one with its own preferences, so that each itinerary is no longer than a given duration and the overall cost due to set up the infrastructure is within a given budget; ii) we formalized the problem as a combinatorial optimization problem in the family of the routing problems with profits, and generalized a MILP model the authors proposed for the single user version; iii) the model was tested on realistic data for the Trebon region in South Boemia, as a step of a larger project aimed at designing a cycle tourist network made of several interconnected itineraries; results showed that the model can be efficiently solved by state of the art solvers, paving the way for decomposition based solution approaches for tackling the network design problem; iv) computational results support the assessment that exploiting the detailed information regarding the preferences of the different classes of users allows for higher quality infrastructure planning; v) commonalities and differences with the planning of a bicycle network when promoting bicycle as a mean of transport are analyzed.

References

Cernà, A., Cernỳ, J., Malucelli, F., Nonato, M., Polena, L., Giovannini, A., 2014. Designing Optimal Routes for Cycle-tourists. Transportation Research Procedia 3, 856–865.

Cox, P., 2012. Strategies promoting cycle tourism in Belgium: practices and implications. Tourism Planning and Development 9(1), 25–39.

Duthie, J., Unnikrishnan, A., 2014 Optimization framework for bicycle network design. Journal of Transportation engineering 140(7).

Fischetti, M., Salazar-Gonzalez, J., Toth, P., 2007. The Generalized Traveling Salesman and Orienteering Problems, in The Traveling Salesman Problem and Its Variations, 609-662, Springer US.

Furth, P.G., Noursalehi, P., 2015. Evaluating the Connectivity of a Bicycling Network. In Transportation Research Board 94th Annual Meeting (No. 15-5612).

Gavalas, D., Konstantopoulos, C., Mastakas, K., Pantziou, G., 2014. A survey on algorithmic approaches for solving tourist trip design problems. Journal of Heuristics 20(3), 291–328.

Heinen, E., Kees, Maat, van Wee, B., 2011. The role of attitudes toward characteristics of bicycle commuting on the choice to cycle to work over various distances. Transportation Research Part D: Transport and Environment, 16(2), 102–109.

Liang, S., Wang, X., Claramunt, C., 2013. Tour Suggestion for Outdoor Activities, in Web and Wireless Geographical Information Systems, LNCS 7820, 54–63.

Parkin, J., Wardman, M., Page, M., 2007. Models of perceived cycling risk and route acceptability. Accident Analysis & Prevention, 39(2), 364–371.

Rybarczyk, G., Wu, C., 2010. Bicycle facility planning using GIS and multi-criteria decision analysis. Applied Geography 30(2), 282–293.

Shcherbina, O., Shembeleva, E., 2014. Modeling recreational systems using optimization techniques and information technologies. Annals of Operations Research 221(1), 309–329.

Smith, H.L., Haghani, A., 2012. A Mathematical Optimization Model for a Bicycle Network Design Considering Bicycle Level of Service, in Transportation Research Board 91st Annual Meeting, 2012 Washington DC, USA, Paper #12-3307.

Vansteenwegen, P., 2011. The orienteering problem: A survey. European Journal of Operational Research 209(1), 1–10.

Vansteenwegen, P., Van Oudheusden, D., 2007. The mobile tourist guide: an or opportunity. Oper. Res. Insight 20(3), 2127.

Wardman, M., Tight, M., Page, M., 2007. Factors influencing the propensity to cycle to work. Transportation Research Part A: Policy and Practice, 41(4), 339–350.