The Green Tourist Trip Design Problem with Time Windows: A Model Application on a Urban Scale

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Abstract: We model a variant of the Tourist Trip Design Problem with time windows. The novelty of the proposed model is that we also take care of the needs of vulnerable users and of the sustainability of the tour in terms of reduction of the level of CO_2 emissions generated by the vehicles associated with the different transportation modes that can be selected to plan the tour. The mathematical formulation of the proposed model consists of three objective functions, with the attempt to generate a green tour which maximizes the number of point of interests (POIs) to visit and, at the same time, the total scores of the visited POIs. The correctness of the proposed model has been tested on a real case, at a urban level. The preliminary results allow to better understand the impact of the sustainability constraints on the tour and to address the direction for further research developments.

1 INTRODUCTION

The tourism is an important economic sector which has always been affected by a growing development, due to its positive impact on improving and sustaining the economy of different countries ((Umurzakov et al., 2022) and (Massidda and Mattana, 2013)). The World Travel and Tourism Council stated that in 2021 the travel and tourism's contribution to global GDP (Gross Domestic Producut) increased by US$1 trillion (+21.7% rise), after around a 54% of decline during the pandemic, confirming that tourism is one of the largest industries that provides a strong impact on the global economic development. The availability of new technologies, like the mobile ICTs, artificial intelligence and sensitive analysis techniques, the massive use of big data and the spread of social networks has had a significant impact on the tourism. The paradigm of Tourism 2.0 changes the digital tourist services from a product-driven environment to a social and customer-driven one: e-business development allows tourists to directly interact with tourism service providers and with other customers to exchange opinions and review visited places. As a consequence, in the last years, it is possible to register the birth of different Tourist Recommender Systems ((Ardito et al., 2019) and (De Maio et al., 2020)), that simplify the life cycle of the tourist experience, filtering relevant information for the users and providing a decision support based on explicit preferences (Kontogianni et al., 2018). Finally, the debate arising from the Sustainable Development Goals (SDGs) of the Agenda 2030 involves also the role of tourism in the near future (see the World Tourism Organisation website https://www.unwto.org/tourism-in-2030-agenda). In particular, the concept of sustainability in tourism is transversal to different development goals: tourism can contribute to use and sale of local products in tourist destinations (zero hunger goal), sustainable tourism can creates jobs (decent work and economic growth goal), tourism can push the investments for smarter and greener cities (sustainable cities and communities and reducing inequality goals), and so on (see (Fakfare and Wattanacharoensil, 2022) and (Alonso-Muñoz et al., 2022)). Under this respect, the research interest in the numerical optimization field is devoted to support the tourist decisions in building appealing and sustainable tours. The problem of helping tourists in the definition of a customized tour is defined Tourist Trip Design Problem (TTDP) (Gunawan et al., 2016). In this problem a tourist usually wants

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to visit a city, rich of attractions, in a limited amount of time. The scope is to build a personalized tour, according to the tourist's preferences, selecting a sequence of POIs to visit. Each POI is characterized by a score related to its attractiveness, a cost and a time window for the visit. The tourist usually can also impose limits about the total budget available for the visits. Moreover, the tourist is able to move from a POI to another using a variety of transportation modes, each of them with different costs (also in terms of CO_2 emissions) and travel times. The scope of this paper is to introduce a variant of the Green Tourist Trip Design Problem (GTTDP), (Divsalar et al., 2022), in which the sustainability of the tour is considered. Under this respect, there are different aspects to be taken into account: the potential attractiveness of the tour, the number of POIs to visit, the time windows of the POIs, the cost and the time duration of the tour, and the quantity of CO_2 released during the movements between POIs. From another perspective, smart and inclusive cities should take care to the needs of the so-called vulnerable road users (VRUs). Traditionally, pedestrians, bicyclists, and motorcyclists are considered VRUs, as well as people with disability, elder people and children (Methorst, 2002). Under this respect, the research interest is more concentrated to reduce crashes involving VRUs (Oxley et al., 2010), to build personalized trips for people with mobility impairments (Darko et al., 2022) or to define information systems and mobile services sharing real-time information and integrating a tour design for VRUs (Scholliers et al., 2017). As argued by (Darko et al., 2022), it is necessary in the next future to propose fully accessible and personalized tours in a broader multimodal mobility context for VRUs, as well as to include useful functionalities into the smart services for the different users' needs. In order to consider all these aspects, a multimodal multiobjective GTTDP with time windows is presented. The rest of the paper is organized as follows: Section 2 reports the literature review in the field and the main contributions of this work. Section 3 describes the mathematical formulation, whereas Section 4 introduces the case study settings and the computational results. Finally, Section 5 reports the conclusions and the future developments.

2 LITERATURE REVIEW

The TTDP is a specific problem defined in the tourism sector, but it can be led back to the more general class of the Vehicle Routing Problems (VRP) with profits (Archetti et al., 2014), in which two different decisions have to be taken: 1) the best customers to be served (not defined a-priori like it happens in the classical VRP) and 2) the routes to be used. If only one route is built, the problem becomes a variant of the Travelling Salesman Problem (TSP), described in the scientific literature by using in some cases alternative denominations. The most diffused denomination is the Orienteering Problem (OP), introduced by (Golden et al., 1987) and deriving from the well known orienteering sport, in which each participant has to maximize the total collected prizes associated with the visited points, returning to the starting point within a certain time. Alternative definitions and variants of the same problem are: the Maximum Collection Problem (Butt and Cavalier, 1994), the Selective Travelling Salesperson Problem (Laporte and Martello, 1990) and the Bank Robber Problem (Awerbuch et al., 1998). Note that, when multiple vehicles are involved, the most investigated variant is the so-called Team Orienteering Problem (TOP). An overview of the OPs that is worth mentioning is reported in the survey of (Gunawan et al., 2016), in which several variants are classified and described: classical OP, TOP (Pessoa et al., 2009), TOP with time windows (Labadie et al., 2012), time dependent TOP (Verbeeck et al., 2014), stochastic OP (Ilhan et al., 2008) and the generalized OP (Geem et al., 2005). The authors, in their conclusions, also identified the tourism trip design as one of the major practical applications of this problem. The TTDP is illustrated in the surveys of (Gavalas et al., 2014) and (Ruiz-Meza and Montoya-Torres, 2022). The authors underlined that the TTDP can be mainly classified in single-objective and multiobjective problems. In the single-objective case, the scope is the maximization of the benefits associated with visiting the POIs. Under this respect, several variants are investigated: presence of time windows denoting the opening and closing times of each POI (Abbaspour and Samadzadegan, 2009); the score of POIs deriving from personal preferences or sensitive analysis (Zheng and Liao, 2019); hotel selection option (Zheng et al., 2020) and, time and budget constraints. In the multiobjective case, different objective functions are considered in the TTDP formulations: minimizing transportation and visiting costs, minimizing waiting times at POIs, maximizing attractiveness of the tour, minimizing travel time between POIs and maximizing the diversity of the selected POIs (see (Castillo et al., 2008), (Lim et al., 2017) and (Huang et al., 2019)). Finally, the authors introduced some future perspective in the tourist trip design, indicating the *green* variant as one of the most promising research areas in the next future. Green and sustainable tourism can be declined in different forms: for example, taking into account emission during movements between POIs, suggesting alternative mobility options to the users, protecting natural areas or potentiating the development of nature tourism and ecotourism. This discussion underlines the timeliness of this work, and a GTTDP with time windows is introduced in the following sections. From the best of our knowledge, the GTTDP was previously investigated only by (Divsalar et al., 2022). The authors introduced a multiobjective and multimodal GTTDP where a mixed-integer linear model is formulated, considering three objective functions: maximizing the total score of the trip, minimizing the total cost and the total CO_2 emission produced by the trip. Under this respect, various transportation modes are considered as possible choice for the tourists in order to move between POIs. Constraints related to travel time are also considered. In this work, an extension of the model in (Divsalar et al., 2022) is proposed, with different novelties:

- three different objective functions are considered: minimizing the total CO_2 emissions and maximizing both the number of visited POIs and the total scores associated with visited POIs;
- the tour is designed considering additional constraints: budget constraint on the total cost (moving and visiting costs) and time windows constraints related to the opening and closing time of the POIs and to the preferences of the tourist for the starting and ending times of the tour; the average visit time at each visited POI is also considered when building the tour;
- a larger variety of transportation modes is taken into account (car, public transport, bike, feet and push scooter);
- additional constraints are incorporated in the model, in order to customize the tour considering only the transportation modes chosen by the tourists, or considering their preferences related to the own physical possibilities (for example, families with children would not like moving by using bicycles or elder people would like avoiding long walking paths);
- the model is tested on a real-setting case study in a urban context (city of Florence).

The detailed description of the mathematical formulation is introduced in the following section.

3 MATHEMATICAL FORMULATION

In order to formalize the model under investigation we adopt the following notation. Let N^+ be the set of n potential POIs to visit, starting from and ending to a fixed point denoted by node 0 and duplicated as node $n+1$. $N = N^+ \cup \{0, n+1\}$, whereas A is the arc set of the complete directed graph induced by N. K is the set of possible transportation modes to realize the visit (car, bus/metro, bike, on foot). For each POI $i \in N^+$ the following parameters are assumed to be known: a score p_i, a cost f_i, i.e., the price of the entrance ticket, a time visit v_i, e_i and l_i, that is, respectively, the opening and closing times. Other parameters are: e_0 and l_0, respectively, the earliest and latest times at which the visit can be planned (the time interval $[l_0 - e_0]$ corresponds to the time window at node 0); T is the maximum travel time determined by all movements between nodes, whereas T_k is the maximum travel time determined by all movements between nodes considering the transportation mode k (clearly, $T_k \leq T$, $\forall\ k \in K$); B is the cost budget available for the visit; c_{ijk}, t_{ijk} and s_{ijk} are, respectively, the cost, the time and the level of CO_2 emission associated with arc $(i,j) \in A$ when travelled by using transportation mode k; M is an arbitrarily large constant. The decision variables are the following: z_i, $i \in N^+$, are binary, each of them equal to one if the POI i is visited, 0 otherwise; x_{ijk}, $(i,j) \in A$, $k \in K$, are binary, each of them equal to one if (i,j) is travelled by using transportation mode k, 0 otherwise; u_i, $i \in N$, are continuous, each of them is the arrival time at node i and, if i is a POI, corresponds to the starting time of the visit at POI i. The three-objective problem is formulated as follows:

$$\text{Maximize} \sum_{i \in N^+} z_i \tag{1}$$

$$\text{Maximize} \sum_{i \in N^+} p_i z_i \tag{2}$$

$$\text{Minimize} \sum_{(i,j) \in A} \sum_{k \in K} s_{ijk} x_{ijk} \tag{3}$$

subject to

$$\sum_{i \in N \setminus \{0\}} \sum_{k \in K} x_{0ik} = \sum_{i \in N \setminus \{n+1\}} \sum_{k \in K} x_{i,n+1,k} = 1 \tag{4}$$

$$\sum_{i \in N \setminus \{j\}} \sum_{k \in K} x_{ijk} = \sum_{i \in N \setminus \{j\}} \sum_{k \in K} x_{jik} = z_j, \forall\ j \in N^+ \tag{5}$$

$$\sum_{k \in K} x_{ijk} \leq 1, \quad \forall\ (i,j) \in A \tag{6}$$

$$\sum_{(i,j) \in A} \sum_{k \in K} t_{ijk} x_{ijk} \leq T \tag{7}$$

$$\sum_{(i,j)\in A} t_{ijk}x_{ijk} \le T_k \quad \forall\, k \in K \tag{8}$$

$$\sum_{(i,j)\in A}\sum_{k\in K} c_{ijk}x_{ijk} + \sum_{i\in N^+} f_i z_i \le B \tag{9}$$

$$u_i + v_i + \sum_{k\in K} t_{ijk}x_{ijk} \le u_j + M(1 - \sum_{k\in K} x_{ijk}),$$
$$\forall\, i \in N, j \in N \setminus \{i\} \tag{10}$$

$$u_i + v_i \le l_i z_i, \quad \forall\, i \in N^+ \tag{11}$$

$$e_i z_i \le u_i, \quad \forall\, i \in N^+ \tag{12}$$

$$u_0 \ge e_0 \tag{13}$$

$$u_{n+1} \le l_0 \tag{14}$$

$$x_{ijk} \in \{0,1\}, \quad \forall\, (i,j) \in A, k \in K \tag{15}$$

$$z_i \in \{0,1\}, \quad \forall\, i \in N^+ \tag{16}$$

$$u_i \ge 0, \quad \forall\, i \in N \tag{17}$$

The objective function (1) is the number of POIs to visit, whereas the objective function (2) represents the corresponding total score of the visit. Both (1) and (2) should be maximized. The third objective function (3), to be minimized, corresponds to the total level of CO_2 emission associated with the visit. Constraint (4) states that the visit starts from node 0 and ends to node $n+1$. Constraints (5) ensure the connectivity of the tour visiting the selected POIs. They also provide the logic condition that an arc incident in any node j can be travelled by any transportation mode only if POI j is selected for the visit. Constraints (6) establishes that each arc (i, j) can be travelled by using one transportation mode at most. Constraints (7) ensure that the total travel time of the tour does not exceed the value of T (the constraint is assumed because the visitor does not like to waste a lot of time on travel). Constraints (8) impose a maximum time budget to be spent for any transportation mode. These constraints allow to limit (or completely forbid) the use of a particular transportation mode, in accordance with the specific needs of the tourist which can be a VRU. Constraints (9) guarantees that the total cost paid for travelling and visiting the POIs remains under the budget limit B available. Constraints (10) are subtour elimination constraints. They state that if an arc (i, j) is visited (i.e., travelled by one transportation mode), then the arrival time at node i plus the duration of the visit at node i and the travel time from node i to node j cannot be greater than the arrival time at node j. Of course, if the arc (i, j) is not visited, then, thanks to the arbitrarily large constant M, the corresponding constraint is not active. Constraints (11) and (12) are time windows constraints at each visited POI. Constraints (11) impose that if POI i is visited, than the starting time of the visit at node i plus the time visit should be within the closing time of POI i and, thanks to constraints (12), the starting time of the visit should be after the opening time of POI i. Constraints (13) and (14) ensure that the visit starts and ends within the time window $[l_0 - e_0]$ established for the visit. Constraints (15) and (16) impose that some decision variables are binary, whereas constraints (17) define the non-negative conditions on the remaining ones. In the following section, some computational experiments related to the real case study are presented.

4 CASE STUDY SETTING AND COMPUTATIONAL RESULTS

The mathematical model illustrated in Section 3 has been applied to the city of Florence in Italy. A set of 20 POIs is considered, whose features, in terms of geographical coordinates, price, average duration of the visit, time windows and score, are reported in Table 1. Note that all data are extracted by using the support of available databases: for the positions, the travel times and distances between POIs (not reported in details for the sake of brevity), a `Python` routine linked with `Google Maps` has been used; the score of each POI has been extracted from the database of MIBACT (Italian Ministry of Cultural Heritage and Activities and Tourism, https://storico.beniculturali.it/mibac/export/MiBAC/index.html#&panel1-1). The spatial distribution of the selected POIs is represented in Figure 1.

Figure 1: Locations of some POIs chosen in the city of Florence.

Five different transportation modes are consid-

Table 1: Features of the 20 POIs chosen in the city of Florence.

ID	POI i	Latitude	Longitude	Cost f_i, (€)	Time window $[e_i, l_i]$	Visiting time v_i, (minutes)	Score p_i
1	Piazza Duomo	43.772904	11.257733	20	[09:30; 17:30]	150	10
2	Piazza della Signoria	43.769306	11.255592	22	[08:15; 18:30]	150	10
3	Ponte Vecchio	43.768459	11.253549	0	[00:00; 24:00]	30	10
4	Galleria degli Uffizi	43.768665	11.25568	20	[08:15; 18:50]	150	10
5	Palazzo Strozzi	43.771527	11.251981	16	[09:30; 17:30]	60	9
6	Museo Galileo	43.767776	11.256297	10	[09:30; 18:00]	60	9
7	Dante's House	43.771016	11.257115	8	[10:00; 18:00]	60	8
8	Basilica of Holy Spirit	43.766924	11.247824	0	[08:30; 18:00]	90	9
9	Synagogue and Jewish Museum	43.773316	11.265698	10	[10:00; 17:30]	120	10
10	English Cemetery	43.77685	11.268549	3	[14:00; 18:00]	60	7
11	Marini's Museum	43.771968	11.249687	6	[10:00; 19:00]	120	7
12	Piazza della S. Annunziata	43.776338	11.260921	4	[07:30; 19:00]	60	8
13	Horne Museum	43.767522	11.259347	6	[10:00; 18:00]	30	7
14	Clet's Workshop	43.764474	11.260829	0	[13:30; 19:30]	60	7
15	Basilica di Santa Croce	43.768737	11.26203	9	[09:30; 17:30]	90	10
16	Parco delle Cascine	43.782497	11.219324	5	[11:00; 19:00]	150	9
17	Complesso di Palazzo Pitti	43.765343	11.249898	22	[08:10; 19:10]	150	10
18	Enzo Pazzagli Art Park	43.768647	11.324149	6	[11:00; 21:00]	150	8
19	Piazzale Michelangelo	43.762464	11.264762	0	[00:00; 00:00]	30	10
20	Gardens and Villa of Castello	43.819098	11.229186	8	[08:30; 18:30]	150	10

ered: car, walking, traditional bike (not electric version), public transportation (tram and bus) and push scooter. The amount of produced CO_2 per transportation mode is extracted from the CO_2 Connect website (www.co2nnect.org): 0.183 kg/km for car, 0 kg/km for walking and bike, 0.065 kg/km for public transportation and 0.126 kg/km for push scooter. Finally, the kilometric cost per transportation mode is equal to € 0.25 for car, € 0.00 for walking, € 0.20 for bike, € 0.35 for public transportation and € 0.50 for push scooter. Note that the costs for bike and push scooter are referred to the most common services of bike sharing and push scooter sharing. It is assumed that the tourist has indicated the maximum duration of the daily itinerary (in our test case 10.5 hours, with a feasible time window set to [9:00;19:30]), the maximum budget (€ 40), the maximum time to be spent for travelling between POIs (60 minutes) and the departure/arrival point of the tour, represented by Santa Maria Novella railway station. To determine a Pareto optimal solution of problem (1)–(17), the lexicographic method is applied, see (Collette and Siarry, 2003). The objective functions (1)−(3) are ranked in order of importance, from best to worst. Then, a sequence of at most three single-objective optimization problems is solved by considering a single objective function at a time, starting with the most important one and proceeding according to the order of importance given to the objectives. However, the optimal value found for each objective is added as a constraint for subsequent optimizations. More specifically, we always keep the objective function (1) of highest priority. In this way, at the first step, the lexicographic optimization leads to the solution of problem (1), (4)−(17). This guarantees that the tour always contains the highest number f_1^* of selected POIs. At the second step, we solve the problem (2), (4)−(17) with the additional constraint $\sum_{i \in N^+} z_i \geq f_1^*$. Let f_2^* be the optimal value of the objective function (2). At this step, in our case, we always obtain a unique optimal solution (otherwise, we should have to optimize this objective). This solution, in correspondence of which we compute the value of the objective function (3), is taken as the desired solution of the original problem. A further Pareto optimal solution is obtained by reversing the order of importance of the second and third objectives. This gives the tourist a choice between two alternatives and enables the evaluation of the advantages of one over the other. The implementation of any optimization problem has been carried out by using GAMS 24.7.4 (GAMS Development Corporation) as the algebraic modelling system, with CPLEX 12.6 (IBM Corporation) as the solver. The code has been executed on a PC Intel Core i7 (2.3 GHz) with 16 GB of RAM. In order to evaluate the effectiveness of the described approach, in terms of CO_2 emissions, of potential savings and of VRUs preferences, a kind of *what-if* analysis has been conducted, considering four cases (called in the following as *scenarios*), on the basis of different settings of the user preferences. These are described as follows:

- **Scenario 1.** The preferences of an eclectic tourist are considered: all transportation modes are fully usable. As a consequence, the budget limit for each transportation mode is equal to the maximum time budget, that is, $T_k = T = 60$ minutes for each $k \in K$.

- **Scenario 2.** The case of a VRU as a tourist is considered. The user is unwilling to walk or ride a bike for more than 20 minutes. As a consequence, the budget limit for each transportation mode is equal to the maximum time budget, except for walking and bike modes, that is, $T_1 = T_4 = T_5 = T = 50$ minutes and $T_2 = T_3 = 20$ minutes.
- **Scenario 3.** Again the case of a VRU is considered, with more extreme requirements. The user is unwilling to walk for more than 10 minutes and could use only e-bikes. As a consequence, the budget limit for each transportation mode is equal to the maximum time budget, except for walking mode, that is, $T_1 = T_3 = T_4 = T_5 = T = 50$ minutes and $T_2 = 10$ minutes. Note that, the e-bike has similar CO_2 emission level of the push scooter, so $s_{ij3} = s_{ij5}, \forall\,(i,j) \in A$.
- **Scenario 4.** A baseline for the evaluation of possible CO_2 emission savings is built, imposing that the tour can allow only private transportation modes: car (fully available) and walking (available only for movements within traffic limited zones). In this way, the greener transportation modes cannot be activated.

Note that all the tests are solved optimally, so the corresponding optimality GAP is omitted. The results obtained by applying for each scenario the lexicographic method described above are reported in the sequel. For Scenarios 1, 2 and 3, the optimal solution of problem (1), (4)−(17) is determined, with a value of the objective function (1) equal to $f_1^* = 9$. As a consequence, $\sum_{i \in N^+} z_i \geq 9$ is the new additional constraint for the subsequent tests. For Scenario 4, the optimal solution of problem (1), (4)−(17) leads to $f_1^* = 7$. As previously described, two further tests are executed for each scenario: the first one considers (2) as the objective function (referred with label **Test X.A**), whereas the second one takes (3) as the objective function (with label **Test X.B**). ”X” indicates the referred scenario. The results are reported in Table 2 organized as follows: column **Test** reports the corresponding setting under investigation, column **POIs** refers to f_1^*; $\mathbf{CO_2}$ reports the CO_2 emission level of the tour; **Score** represents the total score of the selected POIs and **Time** reports the execution time (in seconds) of the test run.

In Table 3, the details about the travel times and the transportation modes activated for each tour are reported. The four tours associated with Tests 1.B, 2.B, 3.B and 4.B (the settings are related to the minimization of the emissions) are also depicted, see Figures 2, 3, 4 and 5.

Table 2: Results of the *what-if* analysis obtained considering four different scenarios.

Test	POIs (f_1^*)	CO_2 (kg)	Score	CPU Time (seconds)
Test 1.A	9	0.052	79	6193.00
Test 1.B	9	0.000	77	0.33
Test 2.A	9	0.874	79	429
Test 2.B	9	0.0699	78	525
Test 3.A	9	2.012	79	88.91
Test 3.B	9	0.993	78	89.13
Test 4.A	7	2.934	56	34
Test 4.B	7	2.934	56	95

Table 3: Results of the *what-if* analysis obtained considering four different scenarios for the transportation modes.

Test	Transportation mode	Minutes
Test 1.A	walking	22.88
	bike	35.67
	car	1.43
Test 1.B	walking	27.20
	bike	31.50
Test 2.A	car	8.50
	walking	8.13
	bike	19.61
	public transportation	20.97
	push scooter	1.62
Test 2.B	walking	14.70
	bike	19.95
	public transportation	8.88
	push scooter	2.32
Test 3.A	car	17.42
	walking	8.13
	bike	27.13
	public transportation	5.52
Test 3.B	car	1.43
	walking	9.00
	bike	11.41
	public transportation	19.36
Test 4.A	car	48.24
Test 4.B	car	48.24

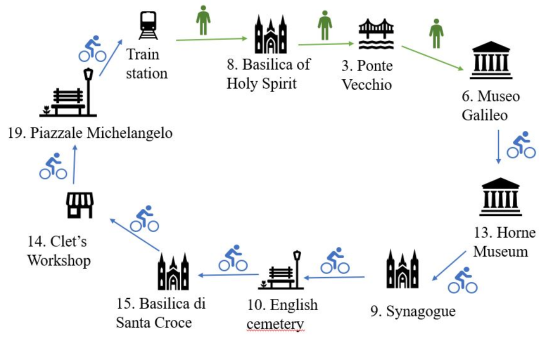

Figure 2: Green tourist tour generated for Test 1.B.

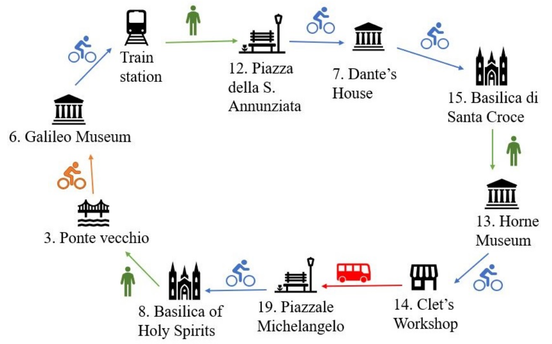

Figure 3: Green tourist tour generated for Test 2.B.

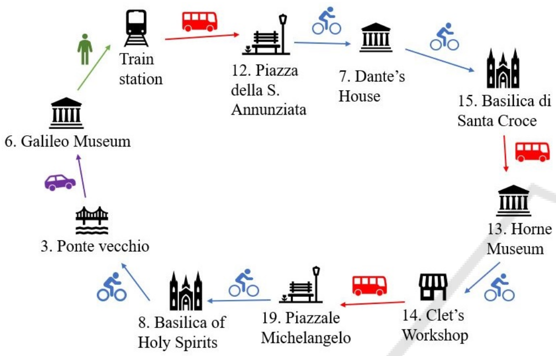

Figure 4: Green tourist tour generated for Test 3.B.

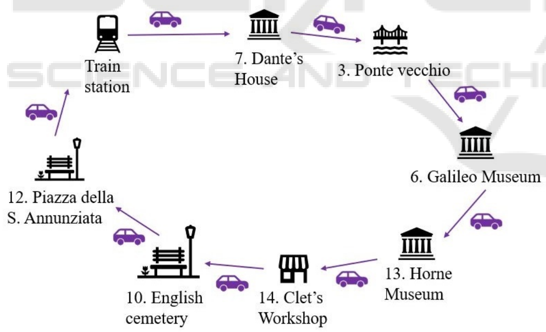

Figure 5: Green tourist tour generated for Test 4.B.

It is worth noting that the lexicographic method can be considered as a suitable approach to generate high quality solutions for different types of tourists. First of all, the choice of assigning the highest priority to the objective function corresponding to the maximization of the number of visited POIs respects the needs of the tourist that generally likes to exploit all the available time for the visit. Although all the solutions obtained are Pareto optimal, some of them seems to be more interesting for the GTTDP. Note that, in Tests 1.B, 2.B and 3.B the reduction of the CO_2 emissions is higher than the loss in the tour scoring. Indeed, comparing Tests 1.A and 1.B, a loss of 2.53% in the tour scoring leads to a reduction of 5.24% of the CO_2 emissions. Similarly, for Scenarios 2 and 3 the reduction of the CO_2 emissions is more than 100%, with a tour scoring loss of 1.27%. The comparison of Scenarios 1, 2 and 3 with the solution obtained in Scenario 4 (the baseline in terms of CO_2 emissions), highlights additional aspects: the reduction of the CO_2 emissions is about 100% for Scenarios 1 and 2 with respect to the solution based on the use of the private car as a transportation mode, and about 45% for Scenario 3. Under this respect, our model empirically shows a good balance between sustainability and the specific requirements of a tourist when acts as a VRU. Finally, note that in Scenario 4 also the tour scoring decreases, compared with the lowest value (77 for Test 1.B): there is a gap equal to 28% between the two solutions. This is due to the typical configuration of the city centre: Florence is characterized by several limited traffic zones, where the POIs are relatively close to each other. For this reasons, the green transportation modes encourage the construction of more attractive tours. This aspect is typical of many ancient tourist cities. Moreover, considering the results reported in Table 3, zero-emission transportation modes are activated quite often. This issue sometimes implies quite longer travel times with respect to other solutions. Finally, the described solutions underline the flexibility of the proposed approach: for each scenario a high quality tour is generated, consuming all the time budget available for the tourists and satisfying their needs in terms of transportation modes.

5 CONCLUSIONS

In this work a multimodal and multiobjective GTTDP is presented for generating a personalized tour compliant with the preferences and the requirements of different kind of tourists. At this stage the proposed optimization model represents only a first step of the development of a more sophisticated decision support tool in a tourism management context. The paradigm of the Tourism 2.0 has definitely introduced the digitalization of tourist services, and several sophisticated ICT platforms has been designed to support several options to *smarter* tourists. The goal of the described approach is to determine a low level of CO_2 emission tour containing a large number of POIs with high scores. Different transportation modes have been considered as choices for the tourist to move between POIs for a daily tour. This tour can be planned to facilitate the tourist category of VRUs, which imposes transportation restrictions. The future steps can involve a more in-depth sensitive analysis on the parameters chosen in the model, and the possibility to extend the experiments to other different urban contexts (larger size cities with more transportation modes). In this case, the possibility of implementing heuristic algorithms cannot be excluded a priori. Under the mathematical perspective, other variants of the optimization model can be investigated by considering multitrip, time-dependent travel times and the variability of the visit duration (dependent of the crowding level of the visited POIs). Under the managerial perspective, further studies can be devoted to evaluate the scalability of the proposed model in a regional context, in which a tourist likes moving between POIs in different cities using long-distance transportation modes (bus, train, private car) and where discouraging the use of private cars has a stronger impact on the CO_2 emission levels. Finally, specific studies can be addressed to the tourist trip design for VRUs with particular disabilities (for example, people in wheelchairs or with low vision) who need to access to POIs, and to transportation modes with specific features.

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