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A multi-day tourist trip planning with multiple time windows and multiple levels of service

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A B S T R A C T

To plan a trip, a tourist should start with collecting information from various sources. Then, he might want to select a number of available points of interest (POI) according to his personal interests and considering many criteria such as, time and budget limitation and the opening and closing times of POIs. Therefore, planning such a daily tour becomes a complex and important task. This problem in its general form is called the Tourist Trip Design Problem (TTDP) in the literature. In this study, we have considered a variant of TTDP in which a number of POIs are taken as mandatory points to visit and the goal is to create a tour in such a way that all mandatory points are included and the total score collected by visiting the optional points of interest are maximized, taking into account different daily opening hours. Moreover, constraints on the length of the route and the maximum budget of the trip should be satisfied. Furthermore, some POIs, are considered to provide multiple levels of services to the visitor. This means that one might select a preferred level of service among the available ones on top of selecting among different POIs according to the associated score and cost. This variant of the TTDP is modeled as a variant of the Orienteering Problem (OP) which we call the Multi-Level Multi-Period Orienteering Problem with Multiple Time Windows (ML-MP-OP-MTW). The proposed integer program is implemented using the CPLEX optimization software. Then, based on available data from the literature, a number of numerical instances are developed and solved. The results show that CPLEX is able to solve only small size instances of the problem in a limited computational time of one hour using a personal computer.

INTRODUCTION

Travel planning is a complex and time-consuming process. Tourists need to collect information from paper and online sources (travel guides, websites, blogs, etc.) about available points of interest. Typically, people create a short list and prioritize the points. Then, one may assume that each POI is assigned a profit according to the personal preferences and priorities of the tourist. The next step will be selection among the interest points. In addition to selecting points, the problem of routing among selected nodes is also computationally attractive. In this study, a budget constraint is set on the total entrance cost of POIs. Moreover, POIs are classified in different categories. To make the tour more diverse, a maximum number of POIs can be selected from each category (a maximum number of museums can be visited during the trip). The objective is to maximize the total profit or score of the visited points. Additionally, each POI may be assigned various service levels (multi-level) depending on its nature. This means that a particular POI might provide only one level of service (natural parks and landmarks), or offer multi levels of service (a hotel or a cafe that provides both regular and VIP services to customers). Furthermore, visit points can be limited to specific time windows (e.g. 7 to 14 and16 to 21). Consequently, the model can be summarized as a Multi-Level Multi-Period Orienteering Problem with Multiple Time Windows (ML-MP-OP-MTW).

BACKGROUND

Travel planning and personalized tourist guides have recently been very much considered in the literature. The Tourist Trip Design Problem (TTDP) was initially introduced by (Vansteenwegen & Van Oudheusden, 2007) in which the Orienteering Problem (OP) is used to model the single tour TTDP. Each point of interest (POI) in a city is assigned a score. The travel times between the POIs are known. Total tour duration should not exceed a pre-determined time limit and the objective is to design a tour so that the collected score or the number of visited points is maximized. During recent years, TTDP has been enhanced in various ways to capture multiple user constraints. According to (Gavalas, et al., 2014),TTDP in its general form may have many practical characteristics such as multiple days tour, various categories of POIs and limiting the number of POIs in each category to be visited during a tour, indexing the points as mandatory and optional, single or multiple hard and soft time windows for each POI, weather dependencies, accessibility restrictions for disabled tourists, budget constraints, or other preferences (e.g. lunch breaks). A multi-day variant of the TTDP has been proposed by (Souffriau, et al., 2010).They have modeled their proposed TTDP as a Multi-Constraint Team Orienteering Problem with Multiple Time Windows (MCTOP- MTW). Besides multiple time windows on the same day and daily maximum duration, this model considers that every location is associated with several attributes, and every attribute has a budget that cannot be exceeded. They developed an Iterated Local Search (ILS) algorithm combined with a Greedy Randomized Adaptive Search Procedure (GRASP) to solve the MC-TOP-MTW. (Zhu, et al., 2012) divide the POIs into two groups: Mandatory and optional. The goal is to maximize the total score considering the weighted profits per user inputs for both groups of POIs during multiple days. Their problem’s constraints include the available budget, the available time for each day, and time windows (same for all days). (Garcia, et al., 2013) included the public transport in to the TTDP and modeled this problem as a time-dependent team orienteering problem with time windows (TD-TOPTW). (Gavalas, et al,, 2015) introduced a more general variant of the TD-TOPTW in which no assumption on periodicity of travel costs are considered. Moreover, available public transport with the transportation times and schedules for different modes of public fleet are taken into account. Another recent variant of the TTDP is modeled as the Orienteering Problem with Hotel Selection (OPHS) by (Divsalar, et al., 2013; 2014) . Given a set of POIs with a profit and a set of hotels, the goal is to determine a number of connected tours that visits a subset of POIs and maximizes the sum of the collected profits. Each tour has a limited length and should start and end in one of the available hotels. They have developed a variable neighborhood search as well as a memetic algorithm to solve the OPHS instances. Other variants of the OP which were used to model the TTDP are the Orienteering Problem with Time Windows (OPTW) and the Multi-Period Orienteering Problem with Time Windows

(MuPOPTW). Iterated Local Search (ILS) approaches for the OPTW has proposed by (Vansteenwegen, et al., 2011) and (Souffriau, et al., 2011). MuPOPTW is introduced by (Tricoire, et al., 2010). Two exact and metaheuristic algorithms are proposed and computational experiments for the OPTW and the MuPOPTW with single and multiple teams are reported. For a more comprehensive literature review, one may refer to the two fairly recent surveys on the OP variants by (Gunawan, et al., 2016) and (Vansteenwegen et al., 2011). In (Rodríguez, et al., 2012) a more interactive system for a customized TTDP is proposed. They introduce a Multi objective variant of the problem in which the most representative solutions are presented to the user. The objectives include the maximization of the utility, the minimization of the distance traveled, and the costs as well as the minimization of the difference between the desired time and the real time spent on each type of visit.

The most similar work to the current research is introduced by (Kotiloglu, et al., 2017). They have introduced a new variant of the TTDP which is modeled as the Multi Period-Multi Constraint-Orienteering Problem-with Multiple Time Windows (MP-MC-OP-MTW). This problem provides a unique combination of features as a variant of the TTDP. It considers visit constraints as mandatory and optional POIs to visit, multiple days, various daily availabilities for each POI in terms of multiple time windows in each day, a limitation on the maximum number of POIs that can be visited from each of the different categories for each day, as well as duration and budget constraints. Because of the similarities, they used the benchmark datasets introduced by (Tricoir et al., 2010) for the MP-MC-OP-MTW to evaluate their proposed method. A Novel Filter-First Tour-Second framework for generating personalized touristic tours is used in which at first mandatory and optional POIs are decided based on a collaborative filtering method, and then an Iterated Tabu Search is implemented to solve the resulted OP over all available POIs.

Although a growing number of researchers are working on the design of comprehensive frameworks for creating personalized tour guides, it is still in its beginning and tackling many realistic features of the problem is still unclear. The focus of this research is to make an extension to the literature and more specifically to the work of (Kotiloglu et al., 2017) to consider multiple service levels for POIs. Looking at the fact that in the real world, some points of interest may provide multiple levels of service and therefore individual tourist demands may be satisfied at various levels of services, this property is added to the earlier variants of the TTDP. Suppose that a tourist who wants to visit a museum or a landmark may request for a different level of service rather than another tourist. This difference in level of service may cause a different level of satisfaction (gaining more or less utility) and a different amount of visiting cost (e.g. visiting full or partial parts of the museum). Therefore, in this research, to the best of our knowledge for the first time in the literature, the POIs are considered as multi-level making them responsive to customers with different levels of demands.

THE MULTI-DAY MULTI-LEVEL PERSONALIZED TRIP PLANNING PROBLEM

Assume that a tourist is planning a - day trip to visit touristic places (POIs) in a city. According to the types of services it offers, each POI can be classified as a multi-level or single-level service provider. There are two sets of points to create a daily tour (a Path and a sequence of visiting points per day): a set of mandatory points (U) includes the points that the user has to visit and the set of optional locations (W) includes the points that the user can choose based on his/her preferences and interests. The set U, which is defined by the user, also reflects personal preferences. All the mandatory and selected POIs among optional ones must be visited during days. There is an available time limit for each day and a total time limit for the whole tour that should be respected. Furthermore, a travel budget limitation should also be considered on the cost of visiting POIs during p days. For each POI and for each day, multiple time windows are placed to consider the various opening and closing hours of POIs in different days. It is also assumed that all mandatory points are one level service providers, and optional points may provide single-level or multi-level services for tourists. Moreover, a specific POI in a particular day may be totally unavailable.

MATHEMATICAL FORMULATION

Accordingly, the proposed problem is formulated as a mixed integer linear programming model. Before presenting the general model, the set of symbols including parameters and decision variables of the model are introduced in the following section.

PARAMETERS

$H = \{1, 2, ..., h\}$: set of service levels.

$V = \{0, 1, ..., n\}$: set of nodes. (0 and n are considered as start and end points of the tour. The rest of nodes are POIs.)

U : set of mandatory POIs.

W : set of optional points.

$C = \{1, ..., n_c\}$: set of categories of POIs.

$P = \{1, ..., n_p\}$: set of days

b_i^{lp} : Opening time of time window l on day p for POI i

n_l : Maximum number of time windows for a POI in a day

$L = \{1, ..., n_l\}$: set of time windows' numbers.

F_p : Available budget on visiting cost of nodes

q_i^h : Profit gained by visiting POI i at service level h .

s_i^p : Time required visiting POI i in period p (service time).

k_{ic} : A binary parameter to indicate if POI i belongs to the category c .

D_p : Maximum time of journey that the user wants to take on day p .

TD : Total available time for the whole tour in p days. TD is obviously less than the summation of Dp over p days.

t_{ij} : Time needed to travel between POI i and j .

m_i^{hp} : The cost of visiting POI i at service level h in period p .

z_i^h : A binary parameter to indicate if POI i provides the service level h .

ϕ_c^p : Maximum number of optional POIs allowed to visit from category c on day p .

Variables

x_{ij}^{hp} : Equals to 1 if POI j is visited at service level h immediately after POI i , in period p ; and equals to 0 otherwise.

α_i^p : Exit time of POI i in period p .

y_i^{lhp} : Equals to 1 if POI i is visited at service level h and during time window l in period p ; and equals to 0 otherwise.

y_i^h : Equals to 1 if POI i is visited in its level h; and equals to 0 otherwise.

$$\max \sum_i \sum_h q_i^h y_i^h \tag{1}$$

$$\sum_{j \neq i} \sum_{h \in H} x_{ij}^{hp} = \sum_{j \neq i} \sum_{h \in H} x_{ji}^{hp} \quad \forall i \in U \cup W , p \in P \tag{2}$$

$$\sum_{i \in V \setminus \{0\}} \sum_{h \in H} x_{0i}^{hp} = \sum_{i \in V \setminus \{n\}} \sum_{h \in H} x_{in}^{hp} = 1 \; \forall p \in P \tag{3}$$

$$\sum_{i=0}^{n-1} \sum_{h \in H} x_{ij}^{hp} = \sum_{j=1}^{n} \sum_{h \in H} x_{kj}^{hp} \leq \xi_k^p \quad \forall p \in P, k \in v_c \tag{4}$$

$$y_i^h = \sum_l \sum_p y_i^{lhp} \quad \forall i \in V, h \in H \tag{5}$$

$$\sum_{h \in H} y_i^h = 1 \; \forall i \in U \tag{6}$$

$$\sum_{h \in H} y_i^h \leq 1 \; \forall i \in W \tag{7}$$

$$\sum_{j \neq i} \sum_{h \in H} y_i^{lhp} = \sum_{j \neq i} \sum_{h \in H} x_{ij}^{hp} \quad \forall i \in V , p \in P \tag{8}$$

$$\alpha_i^p + t_{ij} + s_j^p + \beta . x_{ij}^{hp} \leq \alpha_j^p + \beta \; \forall i, j \in V , p \in P, h \in H \tag{9}$$

$$(a_i^{lp} + s_i^p) y_i^{lhp} \leq \alpha_i^p \leq b_i^{lp} + \beta(1 - y_i^{lhp}) \leq \alpha_j^p + \beta \; \forall i \in V , p \in P, h \in H, l \in L \tag{10}$$

$$\sum_{i=0}^{n} \sum_{j=1}^{n+1} \sum_{h=1}^{n_h} m_i^{hp} x_{ij}^{hp} \leq F_p \quad \forall p \in P, i \neq j \tag{11}$$

$$\alpha_n^p - \alpha_0^t \leq D_p \quad \forall p \in P \tag{12}$$

$$\sum_{p\in P}(\alpha_n^p-\alpha_0^t)\leq TD \tag{13}$$

$$\sum_{i=0}^{n+1}\sum_{j=0}^{n+1}\sum_{h=1}^{n_h}k_{ic}x_{ij}^{hp}\leq\phi_c^p \quad \forall c\in C, p\in P, i\neq j \tag{14}$$

$$x_{ij}^{hp}\leq z_i^h \quad \forall p\in P, i,j\in V, h\in H \tag{15}$$

$$x_{ij}^{hp}\in\{0,1\} \quad \forall i,j\in V \ , \mathrm{h}\in H \ , \mathrm{p}\in P \tag{16}$$

$$y_i^{lhp}\in\{0,1\} \quad \forall i\in V \ \ \mathrm{l}\in L, \mathrm{h}\in H \ , \mathrm{p}\in P \tag{17}$$

$$y_i^h\in\{0,1\} \quad \forall i\in V \ , \mathrm{h}\in H \tag{18}$$

$$\alpha_i^p\in[0,24] \quad \forall i\in V, p\in P \tag{19}$$

The goal is to maximize the total collected profit of visiting optional POIs and is shown in expression (1). Constraints (2) and (3) ensure that each tour starts and ends at the same point. Constraints (4) ensure that only available POIs are considered for each tour. Constraints (5) indicate that each POI can be visited only one time. Constraints (9) and (10) are related to the time windows. Constraints (10) show multiple time windows for each POI, and ensure that a POI can be viewed only in one of its multiple time windows. Constraints (11) and (12) are knapsack constraints that limit the monetary and time budget for each daily tour. Constraints (13) are a maximum length of trip in p days. Constraints (14) ensure that all mandatory POIs are visited exactly once. Constraints (15) are to determine if a particular point has level h of service or not. Constraints (16) to (19) define the range of decision variables.

Model Implementation and Analysis of Numerical Results

The proposed model is implemented in CPLEX IDE Version 12.6 on a PC with a dual core 2GHz CPU and a 2 GB RAM. To generate the numerical instances of the proposed problem, provided data for the MuPOPTW (Tricoire et al., 2010) and MP-MC-OP-MTW (Kotiloglu et al., 2017) are extended and used to validate and test the model.

To generate new instances, the main added parameter is related to the extra level of service provided by some POIs. Some POIs are randomly selected as multi – level service providers which provide two levels of service (h = 2). The remaining POIs are assumed as single service providers. As mentioned, basic data of instances from (Tricoire et al., 2010) and (Kotiloglu et al., 2017) are used. The corresponding scores of POIs are considered as scores of the first level of service and the score of each two – level POI at second level of service is considered as 40% higher than the service level one of that POI. The cost of visiting a POI at service level 2 is assumed to be double the cost of visiting the same POI at service level 1.

In total, 15 instances are developed to test the proposed model. Numbers of POIs in instances are listed in Table 1. All instances created randomly or by modifying previous research data (with instance name TPA). Opening and closing time of each time window, score for each POI and the position of POIs for Instances "TPA_6_10-1" , "TPA_6_20-1", "TPA_6_40-1" and "TPA_6_80-1" are used from (Tricoire et al., 2010), and selecting a POI as mandatory or optional as well as assigning a value for service time of each point are done randomly. For other instances in Table 1, only POI positions are taken from (Tricoire et al., 2010) all other parameters are generated randomly.

Figure 1. shows a sample 3-day tour taken from (Kotiloglu et al., 2017) and adjusted according to the current research problem specifications. This is an example of a possible daily tour visit to a touristic place. In this example, the number of optional POIs is 19 out of 24 POIs. The goal is to maximize the profit of the whole tour. However, other alternative objectives can also be used in the proposed model, such as maximizing the number of visited points or minimizing the travel distance per day (assuming the minimum earned profit as a limitation).

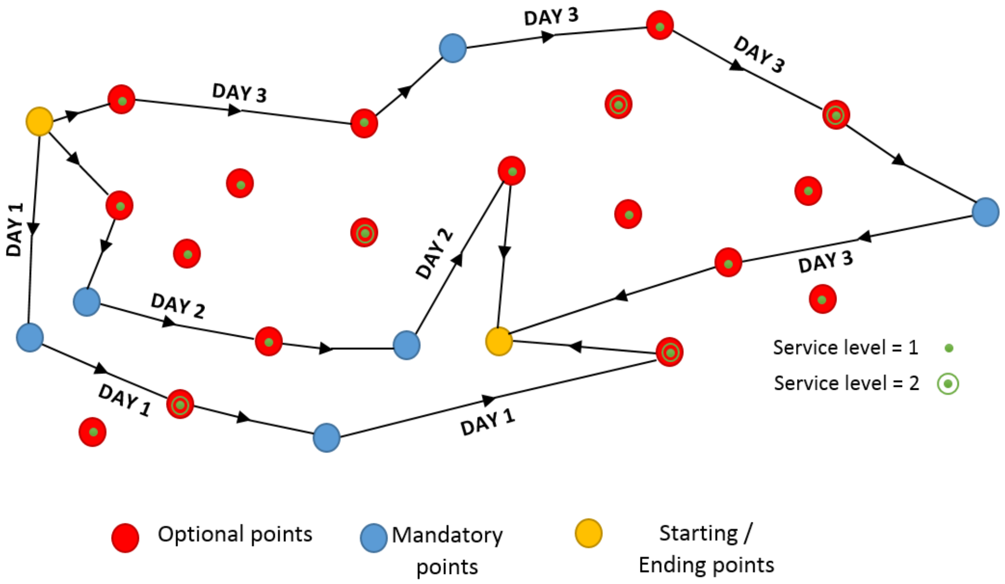

FIGURE 1. A SAMPLE 3-DAY TOUR WITH SERVICE LEVEL

One of the instances used to validate the model is the instance made based on instance TPA_6_10-1 of Tricoire . In this example, 17 points with 9 optional POIs are considered. The starting and ending points (depot) are assumed the same, and the tourist goes back to the starting point at the end of every day. All POIs are categorized in 6 lists. Lists 1,2,3,4,5 and 6 are labels for parks, coffee shops, museums, sights outside the city, attractive places and cinemas, respectively. POIs 0, 1, 2, 10, 12, 14, 16, and 17 are in List 1 and are mandatory and considered as one level service providers. This means that $z_i^2 = 0$ and $z_i^1 = 1$ in the mathematical model. Points 3, 4, 6, 7, 8, 9, 11, 13 and 15 are optional. Only points 3, 5, 6, 7, 11, and 15 are considered as optional POIs which provide two levels of services ($z_i^h = 1 \ \forall h = 1,2$). The computational time of solving this instance by CPLEX was 6.97 seconds, and the optimal collected score is 43931.

The results of implementation of the model in CPLEX and the size of instances are also shown in Table 1. As you can see, for instances larger than 60 POIs, CPLEX cannot solve the problem in a logical time. As an example, for an instance number 14 with 60 POIs, after 9 hours and 34 minutes of computation time, CPLEX was not able to solve the problem to optimality.

In these instances, number of mandatory POIs varies from case to case. For example, for an instance with 17 POIs, 5 POIs are considered as mandatory and for an instance with 40 POIs, 15 points are considered as mandatory. Therefore, the value of the objective function does not directly correlate with the increase in the number of total number of POIs in the city.

TABLE 1. RESULTS FROM A CPLEX WITH DIFFERENT SAMPLE SIZES

Instance number	Instance Name	Number of POIs	Computational time (s)	Optimal Value
1	TPA_6_10-1	10	4:91	54125
2	NTP_12	12	5:26	90149
3	NTP_15	15	6:45	52256
4	NTP_17	17	8:78	43931
5	TPA_6_20-1	20	9:29	102080
6	NTP_25	25	16:40	105150
7	NTP_27	27	21:82	877590
8	NTP_30	30	23:21	146890
9	NTP_32	32	26:92	100289
10	NTP_35	35	52:76	180460
11	TPA_6_40-1	40	64:47	242157
12	NTP_47	47	196	141270
13	NTP_50	50	7363	213760
14	NTP_60	60	insolvable	-
15	TPA_6_80-1	87	insolvable	-

Changes in the value of the objective function in terms of changing the daily travel budget are shown in Figure 2. As can be seen, the value of the objective function does not change when the cost budget is 20 units or higher. Moreover, the variations in maximum number of POIs allowed visiting in each list (ϕ_c^p) and its impact on the objective function and the computation time is shown in Figure 3. It can be seen that for ϕ_c^p equal to two, the computation time is at its highest value. As a result, one of the sensitive parameters in this model is ϕ_c^p.

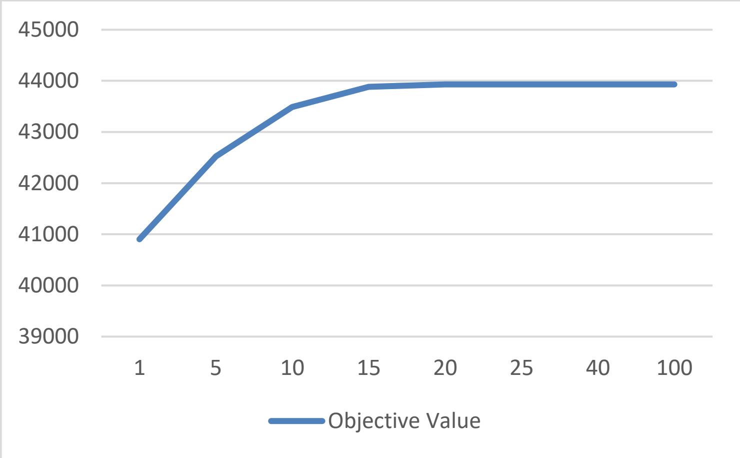

FIGURE 2. CHART OF THE GOAL FUNCTION CHANGES BASED ON TRAVEL BUDGET

FIGURE 3. CHANGES TO THE OBJECTIVE VALUE AND RUN TIME IN TERMS OF LIST POINTS ALLOWED TO VISIT

CONCLUSION

In this paper, the multi-period multi-level orienteering problem with multiple time windows is introduced to model the tourist trip planning problem when taking into account personal constraints and preferences of a tourist who is visiting a touristic place (city). In visiting a point of interest (POI), different tourists may have different levels (types) of demands (expectations). On the other hand, the POI may provide various levels of services. This situation is for the first time in the literature of the tourist personal trip planning, considered in this research. As a result, a mathematical model is provided for the multi-level Tourist Trip Design Problem (TTDP). The goal in this problem is to maximize the personal profit achieved b visiting a number of mandatory as well as optional POIs. To address realistic tourist needs, the proposed model considers multiple user features and constraints, including visit and priority constraints, time dependent availability, time and budget constraints, and maximum number of POIs can be visited from a specific category. The model is implemented in CPLEX and several test instances are generated and solved to validate it. It is observed that the model is able to provide an optimal solution only for small size instances with a few POIs, due to its complexity. Therefore, considering the real-world application of the problem in the field of tourism management, faster solution approaches such as using meta-heuristic methods could be subjects of a future study line.

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