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INTERACTIVE ROUTE PLANNING THROUGH GENERALIZED PICKUP AND DELIVERY TRAVELING SALESMAN PROBLEMS WITH TIME WINDOWS

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Abstract. *This paper presents a route planning to optimize the value in tourism until the tour departs and arrives at accommodation once after having lunch. Since there is often the case that tourists themselves have been making plans for their tourism by using information from guide books and/or websites such as social networking services in recent years. However, it may be difficult to plan optimal tourism for them that suits the preferences of multiple tourist destinations. In the route planning, the tourist shall have various preferences, for example, the must-see tourist destinations, the order of visiting and time. For the must-see tourist destinations and the order of visiting, we introduce generalized pickup and delivery traveling salesman problems. Furthermore, traveling salesman problems with time windows are incorporating for the timing of the visit. To consider that the tourist should not only consider the order of visiting tourist destinations but also the arrival time, we formulate a route planning as generalized pickup and delivery traveling salesman problems with time windows and propose an interactive algorithm to derive a satisfactory route for tourists.*
Keywords: Generalized pickup and delivery traveling salesman problem, Time window constraint, Route planning, Interactive algorithm

1. **Introduction.** In recent years, there is often the case that tourists themselves have been making plans for their tourism by using information from guide books and/or websites such as social networking services. However, it may be difficult to plan optimal tourism for them that suits the preferences from multiple tourist destinations. Therefore, many researchers have been studying the tourism recommender system proposing a route plan choosing a tourist destination such an individual diverse preference efficiently before the clock runs out. The problem of obtaining the shortest path that visits all the given points once has been studied as a traveling salesman problem [1].

In their 1990 paper *The Selective Traveling Salesman Problem*, Laporte and Martello [2] proposed as a problem to choose a route that maximizes the sum of the setting value for each tourist destination under the given constraints. Rao and Jin [3] attempted to solve a traveling salesman problem by analyzing solution space based on complex networks. In addition, the formulation of optimal tour planning that the value of each tourist destination is determined to depend on when a tourist arrives [4], the methods of recommending the value of each tourist destination by receiving information through the Internet [5, 6, 7] have been proposed.

Under these circumstances, in this paper, we consider a route planning to optimize the value in tourism until the tour departs and arrives accommodation once after having lunch. To be more specific, we formulate a route planning as generalized pickup and delivery

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traveling salesman problems with time windows and propose an interactive algorithm to derive a satisfactory route for tourists.

2. Traveling Salesman Problem.

2.1. Formulation of traveling salesman problem.

A traveling salesman problem (TSP) [1] is a problem of visiting all the given points (node) once and obtaining the shortest route among the returning paths to the departure point. There is a cost between each node for n nodes in the traveling salesman problem. The formulation of TSP is as follows:

$$\begin{aligned}
\text{minimize} \quad & \sum_{i\in V}\sum_{j\in V\setminus\{i\}} c_{ij}x_{ij} \\
\text{subject to} \quad & \sum_{j\in V\setminus\{i\}} x_{ij} = 1, \quad i = 1,2,\ldots,l \\
& \sum_{i\in V\setminus\{j\}} x_{ij} = 1, \quad j = 1,2,\ldots,l \\
& \sum_{i,j\in S} x_{ij} \le |S|-1, \quad \forall S \subset V, \quad S \ne V, \quad |S| \ge 2 \\
& x_{ij} \in \{0,1\}, \quad i,j \in V \quad (i \ne j)
\end{aligned} \tag{1}$$

where V is a set of all nodes, x_{ij} is a decision variable that represents an edge between nodes i and j, and c_{ij} expresses a cost between nodes i and j.

2.2. Generalized pickup and delivery traveling salesman problem.

Generalized pickup and delivery traveling salesman problem (GPDTSP) [8] is a combination of general traveling salesman problem (GTSP) and pickup and delivery traveling salesman problem (PDTSP).

In 1969, GTSP was introduced by Henry-Labordere [9] in relation with record balancing problems. GTSP is an extension of TSP as a routing problem between sets of nodes and is a problem of obtaining the shortest path of a route that visits any one of a node where there are m sets of nodes. Here we call this set of nodes a cluster.

Meanwhile, PDTSP proposed by [10] is the addition of precedence constraints to TSP. For example, this constraint expresses that a tourist has to visit the node B before visiting the node A.

GPDTSP can be formulated as

$$\begin{aligned}
\min \quad & \sum_{i\in V}\sum_{j\in V\setminus\{i\}} c_{ij}x_{ij} \\
\text{s.t.} \quad & \sum_{i\in V_p}\sum_{j\in V\setminus V_p} x_{ij} = 1, \quad p = 1,2,\ldots,l \\
& \sum_{i\in V\setminus V_p}\sum_{j\in V_p} x_{ij} = 1, \quad p = 1,2,\ldots,l \\
& \sum_{i\in V} x_{ij} - \sum_{k\in V} x_{jk} = 0, \quad \forall j \in V \quad (i \ne j \ne k) \\
& y_{pq} \ge \sum_{i\in V_p}\sum_{j\in V_q} x_{ij}, \quad p,q = 2,3,\ldots,l \quad (p \ne q) \\
& y_{pq} + y_{qp} = 1, \quad p,q = 2,3,\ldots,l \quad (p \ne q) \\
& y_{pq} + y_{qr} + y_{rp} + \sum_{j\in V_q}\sum_{i\in V_p} x_{ji} \le 2, \quad p,q,r = 2,3,\ldots,l \quad (p \ne q \ne r) \\
& \sum_{i\in V_1}\sum_{j\in V\setminus V_1} (x_{ij} + x_{ji}) \le 1
\end{aligned}$$

$$y_{p1} \geq \sum_{j \in V_1} \sum_{i \in V_p} x_{ji}, \quad p = 2, 3, \ldots, l$$

$$y_{1p} \geq \sum_{i \in V_p} \sum_{j \in V_1} x_{ij}, \quad p = 2, 3, \ldots, l$$

$$x_{ij} \in \{0, 1\}, \quad \forall i, j \in V \quad (i \neq j)$$

$$y_{pq} = 1, \quad p \in Z_q, \quad q = 2, 3, \ldots, l$$

$$y_{pq} \geq 0, \quad q = 2, 3, \ldots, l$$

where

$$y_{pq} = \begin{cases} 1 & \text{visit cluster } q \text{ after cluster } p \\ & \text{(Cluster } q \text{ is not necessarily visited immediately after cluster } p \text{ is visited.)} \\ 0 & \text{otherwise} \end{cases}$$

and let Z_p, $p = \{1, 2, \ldots, l\}$ be a set of cluster numbers that should precede the cluster p.

2.3. **Generalized pickup and delivery traveling salesman problem with time windows.** In the same way, Tamura et al. [11] studied that attractiveness is different depending on the sojourn time and the arrival time of the tourist destination. Thus, the tourist should not only consider the order of visiting tourist destinations but also the arrival time. The traveling salesman problem with the condition that time must be in a specified time frame is called a traveling salesman problem with time windows [12, 13]. In this research, we formulate the tour planning considering the order with the arrival time as the following generalized pickup and delivery traveling salesman problem with time windows (GPDTSPTW):

$$\text{maximize} \quad \sum_{i \in V} \sum_{j \in V \setminus \{i\}} c_i x_{ij} \tag{2}$$

$$\text{subject to} \quad \sum_{i \in V_p} \sum_{j \in V \setminus V_p} x_{ij} = 1, \quad p = 1, 2, \ldots, l \tag{3}$$

$$\sum_{i \in V \setminus V_p} \sum_{j \in V_p} x_{ij} = 1, \quad p = 1, 2, \ldots, l \tag{4}$$

$$\sum_{i \in V} x_{ij} - \sum_{k \in V} x_{jk} = 0, \quad \forall j \in V \quad (i \neq j \neq k) \tag{5}$$

$$y_{pq} \geq \sum_{i \in V_p} \sum_{j \in V_q} x_{ij}, \quad p, q = 2, 3, \ldots, l \quad (p \neq q) \tag{6}$$

$$y_{pq} + y_{qp} = 1, \quad p, q = 2, 3, \ldots, l \quad (p \neq q)$$

$$y_{pq} + y_{qr} + y_{rp} + \sum_{j \in V_q} \sum_{i \in V_p} x_{ji} \leq 2, \quad p, q, r = 2, 3, \ldots, l \quad (p \neq q \neq r) \tag{7}$$

$$\sum_{i \in V_1} \sum_{j \in V \setminus V_1} (x_{ij} + x_{ji}) \leq 1 \tag{8}$$

$$y_{p1} \geq \sum_{j \in V_1} \sum_{i \in V_p} x_{ji}, \quad p = 2, 3, \ldots, l \tag{9}$$

$$y_{1p} \geq \sum_{i \in V_p} \sum_{j \in V_1} x_{ij}, \quad p = 2, 3, \ldots, l \tag{10}$$

$$x_{ij} \in \{0, 1\}, \quad \forall i, j \in V \quad (i \neq j) \tag{11}$$

$$y_{pq} = 1, \quad p \in Z_q, \quad q = 2, 3, \ldots, l \tag{12}$$

$$y_{pq} \geq 0, \quad q = 2, 3, \ldots, l \tag{13}$$

$$r_i \geq t_{0i}, \quad i = 1, \ldots, l \tag{14}$$

$$r_i \geq a_i, \quad i = 1, \ldots, l \tag{15}$$

$$r_i \leq b_i, \quad i = 1, \ldots, l \tag{16}$$

$$r_i - r_j \geq t_{ij} - M s_{ij}, \quad i = 1, \ldots, l, \quad j = 1, \ldots, l \tag{17}$$

$$r_j - r_i \geq t_{ij} - M(1 - s_{ij}), \quad i = 1, \ldots, l, \quad j = 1, \ldots, l \tag{18}$$

$$s_{ij} \in \{0, 1\}, \quad \forall i, j \in V \quad (i \neq j) \tag{19}$$

where the objective function (2) maximizes the total tourism profit. Constraints (14)-(16) are the time window constraints that the tour departs at t_{0i}, arrive after a_i and by b_i at the latest, respectively. Constraints (17) and (18) are the time of day constraints where M is a sufficiently big number and s_{ij} are dummy variables.

We now present an interactive algorithm for deriving a satisficing route plan for a tourist.

Procedure of interactive route planning

Step 1: To express tourists preferences, the tourist destinations are divided into the following 3 groups:

1) set of tourist destinations that must pass,
2) set of tourist destinations that may or may not go through,
3) set of tourist destinations without passing.

Determine the accommodation place, lunch place, and visit time.

Step 2: Solve the generalized pickup and delivery traveling salesman problem with time windows.

Step 3: If the tourist is satisfied with the current route plan, stop. Otherwise, ask the tourist to update the sets of tourist destinations, the accommodation place, lunch place, and visit time and return to Step 2.

3. **Numerical Example.** For investigating the feasibility and efficiency of the proposed method, consider the total tourism maximization problem described in above section. We assume that tourist visits from 13 destinations, 4 lunch places, and 3 accommodation places in Kyoto, Japan, i.e., $l = 20$. The places, their sojourn time and value are shown in the table. Those places are shown in Table 1.

For this GPDTSPTW, we assume that tourist sets starting time 10:00, lunch hour from 12:00 to 13:00, and arrival time at the accommodation place from 18:00 to 19:00 as time window constraints. In addition, suppose that tourist specifies to visit Kiyomizu-dera Temple after lunch.

Then, the GPDTSPTW is solved by branch and bound method [14], and the tourist is supplied with the recommended route of JR Kyoto Station, Yasaka-Shrine, Heian Jingu Shrine, Ginkaku-ji, Marutamachi Jyunidanya, Shimogamo Shrine, Kitano Tenmangu Shrine, Kiyomizu-dera Temple, Ryokan Shimizu.

In this result, assume that tourist is satisfied with the route. Then, it follows that the satisficing solution for the tourist is derived.

4. **Conclusion.** In this paper, we considered a route planning in consideration of a tourist's preference in the sequence that is best for him/her in bounded time, and formulated a generalized pickup and delivery traveling salesman problem with time windows. An illustrative numerical example for a formulated TSP was provided to demonstrate the feasibility of the proposed model. As future work, the proposed formulation can be improved by considering other constraints such as public transportation. These extensions and developments will be discussed elsewhere in the near future.

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Table 1. Visiting places, sojourn time and value

		Sojourn time	Value
Destination			
0	JR Kyoto Station		
1	Kiyomizu-dera Temple	40	10.5
2	Yasaka-Shrine	20	4.5
3	Ginkaku-ji (Jisho-ji)	40	8
4	Kitano Tenmangu Shrine	30	5
5	The National Museum of Modern Art, Kyoto	90	4
6	Kyoto Imperial Palace	60	7.5
7	To-ji Temple	40	7
8	Kodai-ji Zen Temple	30	5
9	Nanzen-ji Zen Temple	60	8.5
10	Eikando Zenrin-ji	40	5
11	Heian Jingu Shrine	45	7
12	Shimogamo Shrine	30	7
13	Tofuku-ji Temple	65	7
Lunch			
1	Marutamachi Jyunidanya	60	7
2	Kyoto Kaji	60	4.52
3	Matsuba	40	5.12
4	Gion Izuju	50	5.85
Accommodation			
1	Ryokan Shimizu		7.5
2	The Kyoto Inn, Hokkaikan Ohanabo		6
3	Kyoto cuisine & ryokan Shiraume		5.5

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