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Invited Review

Orienteering Problem: A survey of recent variants, solution approaches and applications

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ABSTRACT

The Orienteering Problem (OP) has received a lot of attention in the past few decades. The OP is a routing problem in which the goal is to determine a subset of nodes to visit, and in which order, so that the total collected score is maximized and a given time budget is not exceeded. A number of typical variants has been studied, such as the Team OP, the (Team) OP with Time Windows and the Time Dependent OP. Recently, a number of new variants of the OP was introduced, such as the Stochastic OP, the Generalized OP, the Arc OP, the Multi-agent OP, the Clustered OP and others. This paper focuses on a comprehensive and thorough survey of recent variants of the OP, including the proposed solution approaches. Moreover, the OP has been used as a model in many different practical applications. The most recent applications of the OP, such as the Tourist Trip Design Problem and the mobile-crowdsourcing problem are discussed. Finally, we also present some promising topics for future research.

1. Introduction

The term "Orienteering Problem (OP)" was first introduced by Golden, Levy, and Vohra (1987). It is a combination of node selection and determining the shortest path between the selected nodes. The objective is to maximize the total score collected from visited (selected) nodes. In this problem, not all available nodes can be visited due to the limited time budget. Therefore, the OP can be seen as a combination between two classical combinatorial problems, the Knapsack Problem and the Travelling Salesman Problem (TSP) (Vansteenwegen, Souffriau, & Van Oudheusden, 2011a). Since then, several variants of the OP have been introduced, such as the Team OP (TOP), the (Team) OP with Time Windows ((T)OPTW) and the Time Dependent OP (TDOP).

Earlier surveys that situate the OP between other types of routing problems can be found in works of Feillet, Dejax, and Gendreau (2005) and Laporte and Rodríguez-Martín (2007). More recently, Vansteenwegen et al. (2011a) present a comprehensive survey about the OP and its variants, including problem descriptions, benchmark instances and solutions approaches. They also summarize some applications of the OP, such as the home fuel deliver problem and Tourist Trip Design Problem (TTDP). The survey covers research works up to the year 2009. Some possible future research lines have also been mentioned. Gavalas, Konstantopoulos, Mastakas, and Pantziou (2014a) summarize the use of the OP and its extensions to model single tour and multiple tour variants of the TTDP. Possible extensions of the OP that take into account more realistic TTDP issues or constraints are also described. Archetti, Speranza, and Vigo (2014c) present a survey of the broad class of vehicle routing problems with profits and consider the OP as the basic problem of this class. They also briefly cover other variants of the OP, such as the TOP and the Generalized OP. Archetti and Speranza (2014) provide a short survey of the Arc OP and the Team Orienteering Arc Routing Problem as the most recent arc routing problems with profits.

Given these previous surveys, the main contributions of this work are as follows:

- We extend the summary of the survey paper by Vansteenwegen et al. (2011a) by focusing on the most recent papers, not included in the previous surveys, about the OP and its variants including (T)OP, (T)OPTW and TDOP. This summary is presented in Section 2.
- We also extend the recent surveys by Archetti and Speranza (2014); Archetti et al. (2014c) by including 71 additional references to OP-related papers published since 2010 not found in both surveys. They are mainly discussed in Sections 2 and 3.
- We cover a number of new variants of the OP that have been published in the last five years, including the proposed solution

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approaches. For instance, the Generalized OP, the Stochastic OP, the Arc OP, the Multi-agent OP and others. They are discussed in Section 3.
- In Section 4, we extend the survey of the TTDP (Gavalas et al., 2014a) by including the most recent papers related to the application of the OP to the TTDP. We also present a number of recent applications and practical extensions of the OP, such as the mobile-crowdsourcing problem.
- Throughout the survey we provide additional insights and analyze the trends in the different variants of the OP by structuring and classifying the different variants, solution algorithms and applications. We also provide an overview of the available benchmark instances and discuss for which problems instances are not available. The resulting classification enables future researchers to find relevant literature and to analyze which characteristics and OP variants are most popular.
- Finally, we summarize promising topics for future research in Section 5.

2. Classical Orienteering Problem

In this section, a chronological summary of the most recent works related to the classical (T)OP and its variants, including (T)OPTW and TDOP, is presented. The focus lies on the most recent papers not mentioned in previous surveys. All benchmark instances for these variants including their characteristics are available via http://www.mech.kuleuven.be/en/cib/op.

Since we focus on the most recent contributions about the OP, we only present and briefly explain the basic mathematical model for the OP. For the other models, we refer the readers to the survey of Vansteenwegen et al. (2011a). Some mathematical models of more recent extensions of the OP will be presented and discussed in Section 3.

2.1. (Team) Orienteering Problem

The OP is defined as follows. Consider a set of nodes $N = \{1, \ldots, |N|\}$ where each node $i \in N$ is associated with the non-negative score S_i. The start and end nodes are fixed to nodes 1 and $|N|$, respectively. The goal of the OP is to determine a path, limited by a given time budget T_{max}, that visits a subset of N and maximizes the total collected score. It is assumed that collected scores can be added and that each node can be visited at most once. This is in contrast to other problems such as the Attractive Traveling Salesman Problem (Erdoğan, Cordeau, & Laporte, 2010) and other variants of the TSP (Punnen, 2007) where visiting a node close to a customer node is good enough to collect a portion of the score. The non-negative travel time between nodes i and j is represented as t_{ij}. The OP is extended to the TOP where the goal is to determine m paths, each limited by T_{max}, that maximize the total collected score.

The OP can be formulated as an integer programming model (Vansteenwegen et al., 2011a) with the following decision variables: $X_{ij} = 1$ if a visit to node i is followed by a visit to node j, and 0 otherwise. The variables u_i will be used in the subtour elimination constraints and allow to determine the position of the visited nodes in the path.

$$\text{Maximize} \sum_{i=2}^{|N|-1} \sum_{j=2}^{|N|} S_i X_{ij} \tag{1}$$

The objective function (1) is to maximize the total collected score.

$$\sum_{j=2}^{|N|} X_{1j} = \sum_{i=1}^{|N|-1} X_{i|N|} = 1 \tag{2}$$

Table 1
Benchmark OP and TOP instances.

Reference	Problem	Number of instances	Number of nodes $\|N\|$	Number of paths m
Tsiligirides (1984)	OP	18	32	1
		11	21	1
		20	33	1
Chao et al. (1996a)	OP	26	66	1
		14	64	1
Fischetti et al. (1998)	OP	3 × 15	21 to 262	1
		3 × 44	47 to 400	1
		4 × 11	25 to 500	1
		5 × 15	21 to 301	1
Chao et al. (1996b)	TOP	3 × 18	32	2 to 4
		3 × 11	21	2 to 4
		3 × 20	33	2 to 4
		3 × 20	100	2 to 4
		3 × 26	66	2 to 4
		3 × 14	64	2 to 4
		3 × 20	102	2 to 4
Dang et al. (2013b)	TOP	333	100 - 399	2 to 4

Constraints (2) ensure that the path starts from node 1 and ends on $|N|$.

$$\sum_{i=1}^{|N|-1} X_{ik} = \sum_{j=2}^{|N|} X_{kj} \leq 1; \ \forall k = 2, \ldots, (|N| - 1) \tag{3}$$

Constraints (3) ensure the connectivity of the path and guarantee that each node is visited at most once.

$$\sum_{i=1}^{|N|-1} \sum_{j=2}^{|N|} t_{ij} X_{ij} \leq T_{max} \tag{4}$$

Constraint (4) limits the total travel time within the time budget T_{max}.

$$2 \leq u_i \leq |N|; \ \forall i = 2, \ldots, |N| \tag{5}$$

$$u_i - u_j + 1 \leq (|N| - 1)(1 - X_{ij}); \ \forall i = 2, \ldots, |N| \tag{6}$$

The combination of constraints (5) and (6) prevents subtours (Miller, Tucker, & Zemlin, 1960).

2.1.1. Benchmark instances

Vansteenwegen, Souffriau, Vanden Berghe, and Van Oudheusden (2011b) summarize three groups of benchmark OP instances which are available from Tsiligirides (1984), Chao, Golden, and Wasil (1996a) and Fischetti, Salazar-González, and Toth (1998). For the TOP, benchmark instances are available from Chao, Golden, and Wasil (1996b). Dang, Guibadj, and Moukrim (2013b) introduce a new set of larger instances for the TOP. This set is based on the OP instances of Fischetti et al. (1998) with recalculating the time budget per vehicles. The time budget per path is calculated by dividing the time budget of the original OP instance with the number of vehicles of the new TOP instance. In total, there are 333 new instances which can be accessed via https://www.hds.utc.fr/~moukrim/dokuwiki/en/top.

Table 1 summarizes the available benchmark OP and TOP instances. For more details about the characteristics of these sets of benchmark instances, we refer to the survey of Vansteenwegen et al. (2011b) and the original papers.

2.1.2. Solution approaches

Table 2 outlines the most recent papers for both OP and TOP, including the proposed algorithms and benchmark instances. The