Periodic Route Planning of Perishables addressed as a Team Orienteering Problem with fuzzy time windows

Airam Expósito-Márquez, Julio Brito-Santana, and José A. Moreno-Pérez
Department of Computer and Systems Engineering,
Instituto Universitario de Desarrollo Regional (IUDR), Universidad de La Laguna,
38271 La Laguna, Canary Islands, Spain.
Email: {aexposim, jbrito, jamoreno}@ull.edu.es

***Abstract*—This paper considers the problem of planning the collection or delivery of perishable goods. The purpose is to design a number of routes for each day over a given planning horizon while satisfying constraints on route duration, customer service time windows, and customer visit requirements. The objective function of the problem is to maximize the number of nodes visited for collection or delivery. The problem is formulated as a fuzzy version of the Team Orienteering Problem with Time Windows. Time window constraints are not considered hard since some tolerance is allowed. A fuzzy approach that considers fuzzy constraints is used to model and solve this problem. The solution approach uses the TOPTW iteratively to solve the periodic routing and applies a GRASP-VNS hybrid algorithm to find the routes for each consecutive day within the planning horizon.**

***Index Terms*—Perishables, GRASP-VNS hybrid, TOPTW, PVRPTW, Fuzzy Time Windows, Fuzzy TOPTW**

I. Introduction

The supply chain facilitates the transformation from raw materials to products and the distribution of those products to customers. Both processes incorporate tactical and operational planning, and transport and logistics play an important role in business development. The efficiency of the supply chain and therefore of the industry depend on the planning of routes that collect the raw materials for production and those that distribute the processed goods. The arrival of the goods arriving to the production centres and the distribution to final customers are usually treated independently. In transportation routing planning, the firm collects or distributes a set of products from source nodes (i.e., supply points, factories, warehouse,...) to end nodes (i.e., demand points, customers, retail locations,...).

The development of efficient transportation planning is influenced by the characteristics of goods. For example, perishable goods items have short lead and pick up times and must be distributed or collected as quickly as possible due to lost quality. Most perishable freights must be conserved, refrigerated and discarded if a specified time interval has passed. The frequency of pickups and deliveries must be daily or a few days at most. In general, the objective is to reduce costs, but companies must also use their resources efficiently to better serve their customers and ensure product quality. For those organizations that have a limited fleet of vehicles but without capacity limitations, the challenge is to find new approaches to make food collections and deliveries with limited periods and time constraints.

The focus of this work is to meet the challenge of managing periodic collection and delivery of perishable goods in disseminated service areas. These planning routing problems are inspired by real applications, especially the collection of agricultural and livestock products for the elaboration of other products (milk, yogurts, cheeses, ”fourth range” products), and the distribution of these products, processed or unprocessed.

In general, the problems of planning collection and distribution routes have been addressed with the Vehicle Routing Problem (VRP) model and its variants. The VRP [1] optimizes the sequence of nodes to be visited on a set of routes by a collection or delivery trucks. The optimal sequence takes into account the distances between each pair of nodes, the service time and other restrictions imposed on the routes, such as the restrictions on the duration of the route and the delivery and collection time windows.

These problems involve a single period, i.e. pickups and deliveries begin and end in the same planning period, usually a day. However, in real-world applications that concern us, periodic collection and delivery operations have to be planned in a given temporal horizon of several days. Given the characteristics of perishables, the collection and delivery in established periods is mandatory. For example, dairy products are collected on farms every few days, and are used for the preparation of cheeses and yogurts, as well as the distribution of these processed products at points of sale. In general, these problems have been treated with VRP variants, called the Periodic Vehicle Routing Problems (PVRP) [2]. The PVRP requires that each customer be visited in multiple periods of a planning horizon. Such periods can be specified as a given frequency for the visits (e.g. every two days), a given number of visits within the planning horizon (e.g. twice a week), or of a fixed set of periods (e.g. Tuesday and Thursday or Wednesday and Friday).

Another variant introduced to solve vehicle route planning problems is called Routing Problems with Profits or Orien-

978-1-7281-6932-3/20/$31.00 ©2020 IEEE

teering Problems (OP) [3]. In this variant the visit to each node has a certain profit and not all nodes have to be visited. The OP is a combination of choosing a subset of nodes to be visited and determining the shortest path between the selected nodes, so as to maximize the total profits collected from these nodes [4]. While the OP considers only obtaining a path, the Team Orienteering Problem (TOP) considers set of routes [5].

In this paper we propose to address a problem of planning routes for the collection or distribution of perishables where nodes can only be visited at certain times during the planning period within specified time windows. One of the main contributions of this work is the use of a series of TOPTW as a simpler model instead of the PVRPTW, given the characteristics of the periodicity of visits to the nodes in the planning horizon expressed as a frequency. Another contribution is that the time windows to visit the nodes (farm, customers) are not hard, a realistic situation which occurs in many real cases. Therefore, we use a Fuzzy Approach to model and solve this problem considering fuzzy constraints.

Given the complexity of these problems, with instances of a certain size, the use of heuristics and metaheuristics approach is appropriate. Thus, for experimentation and obtaining results, a hybrid metaheuristic to solve TOPTW with fuzzy time window constraints is used. The proposed method combines the Greedy Randomized Adaptive Search Procedure (GRASP) and Variable Neighbourhood Search (VNS).

The rest of the paper is organized as follows. Section II provides a description of the periodic routing problem under study. Section III formulates the fuzzy model associated with time window constraints, TOPTW with fuzzy constraints. In Section IV explains the fuzzy approach to solve the problem. The solution approach proposed for this problem is based on a metaheuristic GRASP-VNS hybrid described in Section V. In Section VI the computational experiments and the corresponding results analysis are described. Finally, some concluding remarks and future works are given in Section VII.

II. Problem Description

This section provides a description of the Periodic Routing Problem with Time Windows for perishables that is considered in this study. This problem deals with the design of several routes for each day of a certain planning horizon $T = \{1, ..., t\}$ of t days. For each day of the planning horizon each vehicle of a fleet of m vehicles follows a route. The routes start and end in the same production plant. Accordingly, a feasible solution of the problem is a set of m routes for each day within the planning horizon carried out by the vehicles of the fleet, where a feasible route is a sequence made up of nodes (farms or customers) to be visited by a vehicle. The objective function of the problem seeks to maximize the number of nodes visited during the planning horizon.

The Periodic Routing Problem with Time Windows for perishables can be formally specified on a complete directed graph $G = (V, A)$. The definition of G includes $V = \{v_0, v_1, ..., v_n\}$ as the vertex set, and $A = \{(v_i, v_j) : v_i, v_j \in V, i \neq j\}$ is the arc set. The vertex set contains the n nodes (farms or customers) and the production plant as v_0. For each arc $(v_i, v_j) \in A$ a travel time $t_{ij} \geq 0$ is known. The production plant, v_0, has a time window $[e_0, l_0]$ that represents the total interval time for the collection or distribution operation of one day. Each node $v_i \in V$, $i \neq 0$, has its own collection or service time $c_i \geq 0$, a time window $[e_i, l_i]$, and a score s_i that represents the amount of collected or distributed products of node (farms or customers) v_i. The maximum duration of every route is represented by W. This limit is determined by the maximum working time of the truck drivers in a working day. A two day limit is placed on the collection or delivery of a products to ensure its quality. The problem under study sets scores s_i equal to 1 and the vehicles have unlimited capacity. Therefore there is no limit on vehicle collection or delivery since the total weight and volume is less than capacity of the trucks.

To summarize, the Periodic Routing Problem with Time Windows for perishables consists of designing m feasible routes for each day of the planning horizon that will be accomplished by the fleet of trucks that collect or deliver perishables while maximizing the number of nodes visited.

III. The Fuzzy Model Formulation

This section presents the mathematical formulation of the problem under study, namely the Periodic Vehicle Routing Problem with Time Windows (PVRPTW) for perishables products. The problem is formulated by means of a Mixed Integer Programming (MIP) problem. The mathematical formulation of the problem corresponding to each day of the planning horizon is stated as a TOPTW model in order to facilitate its resolution. This problem is tackled repeatedly to provide high quality solutions of the periodic problem in the planning horizon. It is not necessary to visit all of the nodes, and each node has an associated score, which is used to calculate the objective. Further, in the corresponding model, the time windows constraints are considered fuzzy; i.e. we consider flexible time windows where a certain tolerance is acceptable. The fuzzy Approach to address the model with fuzzy constraints is presented in the next section.

The components of the TOPTW model are as follows:

Parameters:

- i, j are indices that represent the production plant and nodes, $i = 0, 1, ..., n$, $j = 0, 1, ..., n$.
- k is an index that represents a route; $k = 1, 2, ..., m$, where m is the number of routes.
- s_i is the score associated with the visited of the nodes i; $i = 1, 2, ..., n$. In order to maximize the number of nodes visited, the score is 1 point for each node.
- c_i is the collection or service time of nodes i; $i = 1, 2, ..., n$.
- t_{ij} is the travel time between nodes i and j; $i, j = 0, 1, ..., n$.
- W_k is the maximum duration time for each route k considering travel, collection or services time and waiting times.

e_i, l_i represent the opening and closing times of a node i, respectively; $i = 1, 2, ..., n$.

Decision variables:

X_{ij}^k is a binary variable that is set equal to 1 if vehicle k goes from farm i to j, and $X_{ij}^k = 0$ otherwise.

Y_i^k is a binary variable that is set equal to 1 if node i is visited by vehicle k, and $Y_i^k = 0$ otherwise.

Z_i^k is a real variable that represents the start time of the collection or services at node i

The Team Orienteering Problem with Fuzzy Time Windows (TOPFTW) constraints is formulated as follows:

Maximize:

$$\sum_{k=1}^{m} \sum_{i=1}^{n} s_i Y_i^k \tag{1}$$

Subject to:

$$\sum_{k=1}^{m} \sum_{j=1}^{n} X_{0j}^k = \sum_{k=1}^{m} \sum_{i=1}^{n} X_{i0}^k = m \tag{2}$$

$$\sum_{k=1}^{m} Y_i^k \leq 1 \qquad i = 1, 2, ..., n \tag{3}$$

$$\sum_{j=0}^{n} X_{ji}^k = \sum_{j=0}^{n} X_{ij}^k = Y_i^k \qquad k = 1, ..., m,\ i = 1, 2, ..., n \tag{4}$$

$$Z_i^k + c_i + t_{ij} - Z_j^k \leq M(1 - X_{ji}^k) \qquad k = 1, ..., m,\ i, j \in i, j = 0, 1, ..., n \tag{5}$$

$$Z_i^k + t_{i0} \leq W_k \qquad k = 1, ..., m,\ i = 1, 2, ..., n \tag{6}$$

$$Z_i^k \geq_f e_i \qquad k = 1, ..., m,\ i = 1, 2, ..., n \tag{7}$$

$$Z_i^k \leq_f l_i \qquad k = 1, ..., m,\ i = 1, 2, ..., n \tag{8}$$

$$X_{ij}^k \in \{0, 1\} \qquad k = 1, ..., m,\ i, j = 0, 1, ..., n \tag{9}$$

$$Y_i^k \in \{0, 1\} \qquad k = 1, ..., m,\ i = 1, 2, ..., n \tag{10}$$

$$Z_i^k \geq 0 \qquad k = 1, ..., m,\ i = 1, 2, ..., n \tag{11}$$

Firstly, the mathematical expression (1) represents the objective function of the problem: the total collected o delivered score. Secondly, constraints (2) specify that each route starts and ends at a production plant. Constraints (3) establish that every node (farm or customer) is visited at most once. The set of constraints (4) and (5) establish the connectivity and timeline of each route by the flow conservation rule and the subtour elimination, and M is a large constant in the Big-M method. Constraints (6) guarantee the maximum duration for each route. The time windows constraints are specified by constraints (7) and (8). Finally, constraints (9), (10), and (11) define the variables domains. Note that symbols $\geq_f$ in (7) and $\leq_f$ in (8) denote that constraints are fuzzy.

IV. Fuzzy Optimization approach

The problem was formulated as a optimization problem with fuzzy inequalities in constraints in the previous section. The literature [6], [7] offers approaches to solving these fuzzy optimization problems. Fuzzy Linear Programming (FLP) is a solution approach which considers the fuzzy components included in the problem, and there are different FLP models to choose from. In [6] a basis classification of the different FLP models is proposed. Methodological approaches to provide solutions to FLP models in a direct and simple way are found in [7] and lead to solutions that are coherent with their fuzzy nature. The formulated TOPFTW problem is a model with fuzzy constraints. It is a case where there is a certain tolerance in the fulfilment constraints and consequently the feasible region can be defined as a fuzzy set. Verdegay [6] demonstrate through the representation theorem for fuzzy sets that solutions for a model with fuzzy constraints can be obtained using the following auxiliary model:

$$\begin{aligned} \text{Maximize} \quad & z = cx \\ \text{subject to} \quad & Ax \leq b + \tau(1 - \alpha) \\ & x \geq 0, \alpha \in [0, 1] \end{aligned} \tag{12}$$

where $\tau = (\tau_1, \tau_2, ..., \tau_m) \in \Re^m$ is the tolerance level vector.

In an analogous way, we can replace the fuzzy constraints (7) and (8) of the proposed TOPFTW model by an auxiliary pure mathematical model that contains the following constraints:

$$Z_i^k \geq e_i - \tau_1(1 - \alpha),\ k = 1, ..., m,\ i = 1, 2, ..., n \tag{13}$$

$$Z_i^k \leq l_i + \tau_2(1 - \alpha),\ k = 1, ..., m,\ i = 1, 2, ..., n \tag{14}$$

where $\tau_1, \tau_2 \in \Re$ are the tolerance level or the maximum violations in the fulfillment of time windows constraints provided by the decision maker, and $\alpha \in [0, 1]$. Therefore using this model allows a new solution for each value of α. The decision maker now has a range of solutions according to the variation in α thus this set of solutions is consistent with the fuzzy nature of the problem.

V. Solution Algorithms

Two approaches to deal with the classic PVRPTW [8] can be found In the literature. One approach first solves the problem of assigning all nodes to the days of the planning horizon, and then solves a VRPTW for each day. The other approach repeatedly assigns each node, obtaining partial solutions (subroute) for each day to which that node was assigned, this process is repeated until all nodes are incorporated obtaining routes for each day. The first approach considers the assignment problem with a routing component with the emphasis in assignment and the second approach a routing problem with selection decisions involved.

In PVRPTW, the nodes have a service frequency f_i and a set $C_i \subseteq T$ of allowed combinations of visiting days. In the proposed problem, the Periodic Routing Problem for Perishables, the nodes do not have a fixed combination of visiting days. The nodes only have a visit frequency established within the planning horizon, to be visited every two days.

In order to deal with the Periodic Routing Problem with Time Windows for Perishables, the solution approach begins by assigning all nodes to the first day of the planning horizon and solving the routing problem associated to this day. The routing problem to solve follows the mathematical model presented in the previous section, the TOPTW with fuzzy time windows constraint

The remaining nodes that have not been visited on the first day are assigned to the second day of the planning horizon and again the routing problem TOPTW is solved. On the second day all the remaining nodes must be visited, so that the planning of the first two days can be repeated along the planning horizon.

Routing problems are difficulty to solve [9], and the routing problem presented in this work is NP-hard. Consequently, heuristic and metaheuristic solution approaches are appropriate to solve the Team Orienteering Problem with fuzzy Time Windows. In this regard, a hybrid metaheuristic that combines GRASP (Greedy Randomized Adaptive Search Procedure) [10] and VNS (Variable Neighborhood Search) [11] is proposed to solve each routing problem associated with a day of the planning horizon. This hybrid approach is shown in Figure 1 where $maxIt$ is the maximum number of iterations of the procedure.

GRASP is a multistart two-phase metaheuristic made up of a construction phase and a improvement phase. The construction phase produces a feasible solution and subsequently the solution is improved in next phase. The GRASP construction phase builds a feasible solution step-by-step by adding at random a new farm from a restricted candidate list (RCL) to the current partial solution under construction without destroying feasibility. The construction phase is shown in Figure 2.

The improvement phase performs the solution using a variant of Variable Neighborhood Search (VNS), the Variable Neighborhood Descent (VND). This metaheuristic method consists in changing the neighbourhoods each time the local search is trapped in a local optimum with respect to current neighbourhoods. The method improves iteratively the solution using several movement o neighborhood structures of solution S as $N_k(S)$ for $k = 1, ..., k_{max}$, being k_{max} the number of neighborhood structures. The VND procedure is shown in Figure 3.

GRASP is used as an outer framework for diversification, and VND for intensification. Nevertheless, in the proposed solution approach the value of k is used for control the size of movements that will be described below. The initial solution obtained by GRASP is improved by using a VND with three movements:

- *k-chain move*. Take a chain of k consecutive nodes in a route of the solution and move it to another part of the

```
function GRASP(maxIt, sizeRCL, k_max)
  1) readInput()
  2) for Iter = 1,... ,maxIt do
       a) solution = GRASPConstPhase(sizeRCL)
       b) solution = VND(solution, k_max)
       c) updateSol(solution, bestSolution)
  3) return bestSolution
end GRASP
```

Fig. 1. GRASP

```
function GRASPConstPhase(sizeRCL)
  1) Initialize the partialSolution with m
     empty routes
  2) While it is possible to visit new
     nodes
       a) CL = ∅
       b) For each node i ∈ I
            i) Find the best feasible triplet
               (i, j, k) to insert this new POI
               i in partialSolution according to
               greedy time function f(i, j, k)
           ii) Add the feasible triplets
               (i, j, k) to the Candidate List
               CL
       c) Create the Restricted Candidate
          List, RCL, with the best sizeRCL
          triplets (i, j, k) from CL according
          to f
       d) Select a random triplet (i, j, k)
          from RCL
       e) Update the variables of route k
          by inserting node i at position j
  3) return partialSolution
end GRASPConstructPhase
```

Fig. 2. GRASP construction phase

```
function VND(solution, k_max)
  1) k = 1
  2) While (k ≤ k_max)
       a) Find the best solution sol' in
          N_k(sol)
       b) If (sol' is better than sol)
            i) Take sol = sol' and k = 1
       c) Else
            i) Take k = k + 1
  3) return solution sol
end VND
```

Fig. 3. ariable Neighborhood Descen (VND)

same route or in other route.

- *2-opt move*. Select two edges in a route and crosses the route over itself reordering the nodes so the crossing is removed.
- *Insertion move*. Try to insert nodes that have not yet been visited in the current solution while maintaining its feasibility.

The neighbourhood structure of the VND is a combination of the movements described above. The first two movements, $k - chain$ and $2 - opt$, try to reduce the total travel time of the solution and then the $Insertion$ move tries to insert not visited nodes in the solution.

VI. EXPERIMENTATION

The results of the computational experiments carried out in this study are described in this section. The purpose of the experiments is to solve the Periodic Routing Problem with Time Windows for Perishables and to test the proposed solution approach.

Complete data about the collection of perishables or distribution of this real world problem is unavailable at present. Instead we only have access to several attributes. Accordingly, some instances for PVRPTW [12] were adapted in order to test the solution approach and solve the proposed problem. These instances are $p01$, $p07$, $p11$, $p12$, and $p17$, and they provide data regarding the location of nodes, time windows, and service duration. The information about visit combination for each node is set in order to guarantee that the product is at least collected after two days.

The number of routes for each day of the planning horizon and the days of the planning horizon is also introduced. Details about the instances data used is given in Table I.

Instances	Farms	Routes per day	Max. time per route	Days
$p01$	48	3	500	6
$p07$	72	5	500	6
$p11$	48	3	500	6
$p12$	96	6	500	6
$p17$	72	4	500	6

TABLE I
DETAILED DATA OF INSTANCES

As regards parameters of the hybrid solution approach, RCL size values should be set for GRASP, k_max for VND, and the tolerance levels associated with fuzzy optimization approach. Tolerance levels τ_1 and τ_2 applied in time windows constraints are 15% of e_i and l_i respectively, with α values in $0.2, 0.4, 0.6, 0.8,$ and 1.0. Details regarding the parameter values can be seen in Table II. The solution approach runs 1000 times for each of the instances and parameter values set in the computational experiments. The computational experiments were carried out on a machine equipped with a Intel Core i7-3610QM CPU processor at 2.30 GHz and 16 Gb RAM.

Parameter	**Values**
Size of RCL	$sizeRCL \in \{3, 5, 7, 10\}$
VND parameter	$k_{max} \in \{2, 3, 4, 5\}$
Values of alpha	$\alpha \in \{0.2, 0.4, 0.6, 0.8, 1.0\}$
Tolerance level 1	τ_1 is 15% of e_i
Tolerance level 2	τ_2 is 15% of l_i

TABLE II
THE VALUES OF THE PARAMETER FOR THE GRASP-VNS HYBRID

Table III shows the computational experiment results for the best solutions obtained varying α. The first column of the table includes the instance and values for α. The remaining columns show several characteristics of the best solutions. The second column shows the visited nodes in the planning horizon compared with the total number of nodes in the instance. Finally, the Execution Time column shows the computing time to obtain the solutions measured in seconds.

Table III indicates the maximum number of visited nodes in the solutions, and the results reveal that for some instances it is not possible to visit all farms. The results indicated in bold are those where all nodes were visited within the planning horizon. Specifically, for $\alpha = 1$ with no tolerance in the time window constraints, it is not possible to visit all nodes for instances $p01$, $p07$ and $p17$. However, as the tolerance increases in the time window constraints by decreasing the α value, the softening of the constraints allows all nodes within the planning horizon to be visited. In the case of $p11$ and $p12$, it is not necessary to soften the time windows constraints to visit all nodes within the planning horizon.

VII. CONCLUSIONS AND FURTHER RESEARCH

In this study, we propose a Soft Computing approach to deal with a Periodic Route Planning with Time Windows of Perishables within the context of as a Team Orienteering Problem with Time Windows with Fuzzy Time Windows constraints (TOPFTW). The proposed approach incorporates the assignment of customers to the planning horizon days and a GRASP-VNS hybrid solution as a way to solve the problem and obtain quality solutions in reasonable time. The computational experiments results show that the proposed approach can solve the problem by considering solutions that are consistent with its fuzzy nature. Nevertheless, if softening of time window constraints is not allowed, then there are some

Instances/ Alphas	**Best Solutions**	
	Visited nodes	*Execution Time*
p01		
α = **0.2**	**48/48**	**0,0028**
α = **0.4**	**48/48**	**0,0032**
α = **0.6**	**48/48**	**0,0044**
$\alpha = 0.8$	$44/48$	$0,0027$
$\alpha = 1.0$	$41/48$	$0,0027$
p07		
α = **0.2**	**72/72**	**0,0404**
α = **0.4**	**72/72**	**0,0116**
α = **0.6**	**72/72**	**0,0108**
α = **0.8**	**72/72**	**0,0063**
$\alpha = 1.0$	$62/72$	$0,0027$
p11		
α = **0.2**	**48/48**	**0,0039**
α = **0.4**	**48/48**	**0,0022**
α = **0.6**	**48/48**	**0,0023**
α = **0.8**	**48/48**	**0,0015**
α = **1.0**	**48/48**	**0,0027**
p12		
α = **0.2**	**96/96**	**0,0039**
α = **0.4**	**96/96**	**0,0022**
α = **0.6**	**96/96**	**0,0023**
α = **0.8**	**96/96**	**0,0015**
α = **1.0**	**96/96**	**0,0027**
p17		
α = **0.2**	**72/72**	**0,0066**
α = **0.4**	**72/72**	**0,0133**
α = **0.6**	**72/72**	**0,0138**
α = **0.8**	**71/72**	**0,0196**
$\alpha = 1.0$	$68/72$	$0,0027$

TABLE III
COMPUTATIONAL EXPERIMENT RESULTS FOR BEST SOLUTIONS

instances where it is not possible to visit all nodes. In addition, as time windows constraints become more flexible, the number of visited nodes in the solutions within the planning horizon increases.

Future research will extend experimentation considering instances with data from a real-life case of perishables industry, specifically in the dairy industry with the problem of collecting milk from small local farms with limited isothermal facilities while preserving the quality of the perishable product. The proposed solution approach can be adapted and tested to solve the classic instances of PVRPTW. The behavior of other metaheuristics, enhanced mechanisms in GRASP, and neighbourhood structures in VND will also be studied.

ACKNOWLEDGMENT

Contributions from Airam Expósito-Márquez are supported by la Agencia Canaria de Investigación, Innovación y Sociedad de la Información de la Consejería de Economía, Industria, Comercio y Conocimiento and by the Fondo Social Europeo (FSE).

REFERENCES

[1] P. Toth and D. Vigo, *Vehicle Routing: Problems, Methods, and Applications, Second Edition*, ser. MOS-SIAM Series on Optimization. SIAM, 2014, no. 18.

[2] P. M. Francis, K. R. Smilowitz, and M. Tzur, *The period vehicle routing problem and its extensions*. Springer, New York, 2008, pp. 73–102.

[3] P. Vansteenwegen and A. Gunawan, "Orienteering problems: Models and algorithms for vehicle routing problems with profits," in *EURO Advanced Tutorials on Operational Research*. Springer Nature Switzerland AG, 2019.

[4] P. Vansteenwegen, W. Souffriau, and D. Van Oudheusden, "The orienteering problem: a survey," *European Journal of Operational Research*, vol. 209, no. 1, pp. 1–10, 2011.

[5] I. Chao, B. Golden, and E. Wasil, "The team orienteering problem," *European Journal of Operational Research*, vol. 88, no. 3, pp. 464–474, 1996.

[6] J. L. Verdegay, "Fuzzy optimization: models, methods and perspectives." in *In proceeding 6th IFSA-95 World Congress.*, 1995, pp. 39–71.

[7] M. Delgado, J. Verdegay, and M. Vila, "A general model for fuzzy linear programming," *Fuzzy Sets and Systems*, vol. 29, pp. 21–29, 1989.

[8] J.-F. Cordeau, G. Laporte, and A. Mercier, "A unified tabu search heuristic for vehicle routing problems with time windows," *Journal of the Operational Research Society*, vol. 52, no. 8, pp. 928–936, 2001.

[9] J. K. Lenstra and A. H. G. R. Kan, "Complexity of vehicle routing and scheduling problems," *Networks*, vol. 11, no. 2, pp. 221–227, 1981.

[10] M. G. Resende and C. C. Ribeiro, *Optimization by GRASP: Greedy Randomized Adaptive Search Procedures*. Springer, 2016.

[11] P. Hansen, N. Mladenović, and J. A. Moreno Pérez, "Variable neighbourhood search: methods and applications," *Annals of Operations Research*, vol. 175, no. 1, pp. 367–407, 2010.

[12] C. J-F, L. G, M. A, and Correspondence, "A unified tabu search heuristic for vehicle routing problems with time windows," *Journal of the Operational Research Society*, vol. 52, pp. 928–936, 08 2001.