Daily Wildfire Patrol Routing for Early Detection and Prevention: a case study in the south of France

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Abstract: In the context of climate change, wildfires are becoming more frequent and intense worldwide, expanding risks to previously unaffected northern regions. One of the most effective strategies for wildfire prevention and early detection is surveillance and intervention patrols. In France, these patrols are primarily conducted by the National Forest Organization relying on daily weather conditions and expert judgment to determine patrol routes. Our study focuses on designing a new approach to optimize surveillance patrols while taking into account real-world operational constraints. Surveillance and intervention patrol can be formulated as a team orienteering problem with time windows and time-dependent scores. In this work, a case study is conducted using real-world data in a department in the South of France. In which we model the daily patrols as the team orienteering problem with time windows and time-dependent profit, where a fleet of vehicles must cover high-risk areas based on tourist activities, fire risk estimations and weather conditions. Patrol routes are restricted by the duration of the daily shift, therefore not all locations can be visited and the focus must be on the riskiest ones. Each location should be visited during a specific time window, within which the periods carry a different score based on the fire risk levels variations throughout the day. Each point type (e.g. prevention or extinguishment) requires a different intervention time. The objective is to maximize the daily total score of each route. A literature review is also carried out in this work.

Keywords: Patrol routing problem, Extreme weather events, Wildfire, Optimization, Decision making

1. INTRODUCTION

Climate change is leading to an increase in the frequency and intensity of extreme weather and climate events such as heatwaves and droughts. These events are accompanied by a rise in wildfire risks, even affecting areas that were previously less exposed. According to the work of Cunningham et al. (2024), the frequency of wildfires has doubled, increasing by a factor of 2.2 globally over the past two decades. A wildfire is defined as a fire affecting a minimum area of one hectare. The risk of wildfires arises from various human, environmental, and climatic factors. Among these, climate plays a key role. In this regard, regions with hot climates and periods of drought are particularly vulnerable.

Wildfires have serious economic and environmental consequences, and can even result in the loss of human lives. In Europe, several hundred thousand hectares of forests and land are ravaged by wildfires every year. The latest annual report on wildfires by the European Commission (San-Miguel-Ayanz et al., 2024) highlights that wildfires destroyed in Europe the equivalent of twice the area of Luxembourg, with more than 500,000 hectares burned in 2023. In the south of France, more than 3,000 forest fires have been recorded every year since last decade, affecting between 10,000 and 17,000 hectares of forested land annually.

In the face of frequent wildfire risks, the state and local communities play an important role in prevention and emergency response efforts. In France, the Natural Risk Prevention Plan (PPRN) is developed as part of a policy aimed at preventing and raising awareness among

residents about natural risks, in order to reduce their vulnerability. However, prevention and intervention plans can prove insufficient in extreme wildfire management situations, as they are considered reactive management strategies. There is still room for carrying out more active strategies to prevent wildfire risks and improve the safety of emergency services. This could involve planning daily patrol in high-risk areas, implanting ecological barriers and fire/fuel breaks in forest areas, and installing monitoring points at strategic locations.

In this paper, we are interested in the daily patrol routing problem for wildfire prevention. A study case is developed based on wildfire prevention strategy applied in the department of Gard in the south of France. In which, the daily patrol missions is ensured by agents of the National Forestry Office (NFO) and volunteer firefighters of the local Departmental Fire and Rescue Service (DFRS) using a fleet of vehicles during the summer season. According to the daily weather conditions and the tourist activities, a set of points with different time-dependent risk levels in forested areas is estimated using the existent prevision models. The risk level represents the probability of fire outbreaks within a time windows. Each vehicle, with a NFO agent and a volunteer firefighter on-board, starts its patrol tour at 11am and ends at 7pm. The objective is to determine a set of patrol tours that maximizes the total number of visited points and the sum of the risk levels of the visited points.

The considered daily patrol routing problem can be considered as an variant of the vehicle routing problem with time windows and profit. However no customer demand or vehicle capacity is taken into account in the patrol routing problem. More precisely, the considered patrol routing problem can be modeled as a team orienteering problem with time windows and time-dependent profit. The team orienteering problem is initially introduced by Tsiligirides (1984) and several variants exist of the team orienteering problem that take time window constraints into account (Righini et al., 2006). The team orienteering problem with time windows and time-dependent profit is initially studied by Yu et al. (2019). Most of the existing literature on the team orienteering problems with time are focused on route-planning for tourists interested in visiting multiple points of interest (Gavalas et al., 2014; Gavalas et al., 2016; Vansteenwegen et al., 2009b; Vansteenwegen et al., 2009a).

The rest of this paper is organized as follows. Section 2 reviews the main variants of the team orienteering problem with time windows. Section 3 presented the cased study of the considered daily patrol problem in the department of Gard in the south of France, before the conclusion at Section 4.

2. LITERATURE REVIEW

In the literature, the team orienteering problem is a variant of the class of vehicle routing problems with profit, in which each point is associated with a profit value. Unlike the classical vehicle routing problems where the set of points to visit is predetermined, in the team orienteering problem the selection of customers to serve needs to be determined in order to maximize the total collected profit, therefore not all customers can be visited during a route limited by a maximum duration (Archetti et al., 2014). The team orienteering problem with time windows is an extension of the team orienteering problem, where each location must be visited in a specific timeframe. The latter has been widely studied in the literature, and various approaches have been proposed in the literature (Labadie et al., 2012; Lin & Yu, 2012; Vansteenwegen et al., 2009a). The team orienteering problems with time windows have received less attention compared to the classical the team orienteering problem. In this section, we are interested to the team orienteering problem with time windows and its variants considering additional constraints including mandatory visits, variable profits, partial scores, or time depending scores.

Lin & Yu, (2017) addressed the team orienteering problem with time windows and mandatory visits where a set of customers must be visited out of the total list. The objective is to maximize the total profit, while visiting a location at most once and ensuring that the mandatory points are visited. A mixed integer linear programming model and a multi-start simulated annealing heuristic are developed to tackle this problem.

Marzal & Sebastia, (2022) deal with the team orienteering problem with time windows and variable profits, where the profit associated with each location varies depending on the time spent within a specific time window. Authors proposed a mathematical model and an Iterated Local Search algorithm for this problem. This variant can be applied on case studies, such as tourist trip planning where spending more time at a specific location can be more satisfactory than visiting many places briefly, or reconnaissance vehicle routing where staying longer at a specific location to gather more data is more valuable than to quicky move from point to point. Marzal & Sebastia, (2024) improve their proposed Iterated Local Search algorithm to obtain a faster solution.

Granda & Vitoriano, (2024) focus on the team orienteering problem with variable time windows, where the time windows dynamically adjust based on the solution routes generated by the model. They proposed a mixed integer linear programming for the problem solving. The proposed model can be applied in the context of wildfire containment: as the model determines routes that limit the spread of the fire, the time windows for visiting critical points are extended accordingly. In this problem, the nodes don't have an associated profit, but rather have an associated loss, if the node is affected by the spread. The objective is to minimize the loss, which is to minimize the number of affected nodes. Granda & Vitoriano, (2025) continue their previous work by presenting a greedy constructive heuristic to solve real size instances of the team orienteering problem with variable time windows.

Yu, et al., (2019) studied the team orienteering problem with time windows and partial scores applied to tourist trip planning. In this variant, each location offers several leisure activities, each associated with a partial profit. A mathematical model and a discrete Particle Swarm Optimization is proposed to solve the problem. The objective is to maximize the total profit, by selecting which activities to do at each visited location. Yu, Jewpanya, et al., (2019) propose a mathematical model and a hybrid artificial bee colony algorithm to solve the team orienteering problem with time windows and time-dependent scores applied to tourist trip planning. In this problem, each location must be visited within a specific time window but the score (or profit) associated with a location varies depending on the time of day such as morning, afternoon or evening, reflecting differing levels of visitor satisfaction.

3. A CASE STUDY OF THE DAILY PATROL PROBLEM IN THE SOUTH OF FRANCE

In our work, we are interested in the daily wildfire patrol routing for early detection and prevention. A study case is applied in the department of Gard in the south of France. During the summer season, the National Forestry Office and the firefighters, using a fleet of vehicles patrol the forests to prevent fire ignition. Each vehicle is comprised of a forest ranger and a firefighter to combine their expertise which enables more effective identification and assessment of fire risks.

Each day, patrol routes are planned based on tourist presence in forested areas and fire ignition risk levels, which are derived from daily weather reports. Every potential location is assigned a risk level, and locations with higher risk should be prioritized in the routing decisions.

Moreover, these risk levels are time-dependent, as fire risk at each location can vary throughout the day, increasing or decreasing depending on the time. The risk level for each point can be interpreted as a score or a profit. The patrols start and end in a particular fire station, and are subject to a maximum duration of eight hours per day.

As illustrated in Figure 1, the considered daily wildfire patrol problem can be defined as follows: considering a complete graph $G = (V, A)$ models the road network, where $V = \{0,1, \dots, n\}$ is the set of nodes and A the set of arcs. The set of nodes is composed of the depot (denoted by 0) and n points (denoted by 1, …, n). Each point is associated with a risk value with in a time windows and a service duration. A set of vehicles initially parked at the depot can be employed to ensue different patrol tours. Each tours has a maximum duration of 8 hours with one hour break. It is assumed that the number of vehicles is not sufficient to visit all points. The objective is to maximize the total accumulated risk level of the visited locations within this time frame. The formulation of the daily wildfire patrol problem is similar compared to the team orienteering problem with time windows and time-dependent scores as in (Yu et al., 2019).

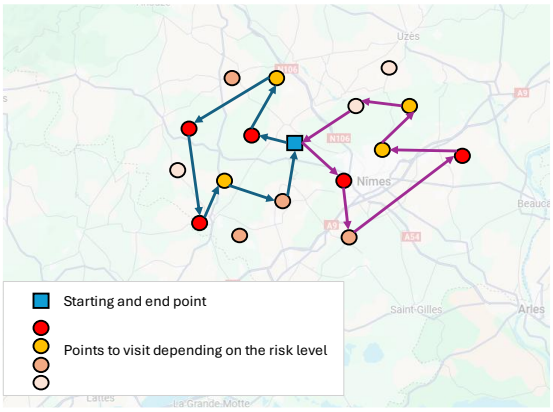

Figure 1 : The daily wildfire patrol problem for early detection and prevention in the south of France.

4. CONCLUSION

In this paper, we are interested in daily wildfire patrol problem that can be formulated as the team orienteering problem with time windows and time-depend scores. A literature review is carried out focusing on several key variants of the team orienteering problem with time windows. In the literature, the team orienteering problems with time windows is mainly applied for the organization of tourist tours. Our work focus specifically on the application of the team orienteering problem with time windows on the daily wildfire patrol problem. In this context, each location is associated with a risk level, represented as a time-dependent profit, and the objective is to maximize the total accumulated profit by visiting the most critical (i.e., riskiest) points within given time windows. This application aims to prioritize areas with the highest risk of fire ignition during patrols. As a continuation of this work, we are working on the design of a Mixed-Integer Linear Programming model as well as a metaheuristic algorithm for the efficient resolution of this problem.

5. REFERENCES

Aghdasi, H.S., Saeedvand, S. and Baltes, J., 2019. A multi-objective evolutionary hyper-heuristic algorithm for team-orienteering problem with time windows regarding rescue applications. The Knowledge Engineering Review, 34, p.e19.

Archetti, C., Speranza, M.G. and Vigo, D., 2014. Chapter 10: Vehicle routing problems with profits. In *Vehicle routing: Problems, methods, and applications, second edition* (pp. 273-297). Society for Industrial and Applied Mathematics.

Cunningham, C. X., Williamson, G. J., & Bowman, D. M. (2024). Increasing frequency and intensity of the most extreme wildfires on Earth. Nature Ecology & Evolution, 1-6.

Gavalas, D., Konstantopoulos, C., Mastakas, K. and Pantziou, G., 2014. A survey on algorithmic approaches for solving tourist trip design problems. Journal of Heuristics, 20(3), pp.291-328.

Gavalas, D., Konstantopoulos, C., Mastakas, K., Pantziou, G. and Vathis, N., 2016. Efficient metaheuristics for the mixed team orienteering problem with time windows. Algorithms, 9(1), p.6.

Granda, B. and Vitoriano, B., 2024. The team orienteering problem with variable time windows. International Transactions in Operational Research.

Granda, B. and Vitoriano, B., 2025. A Greedy Constructive Heuristic for Solving the Team Orienteering Problem with Variable Time Windows. International Journal of Computational Intelligence Systems, 18(1), p.69.

Labadie, N., Mansini, R., Melechovský, J. and Calvo, R.W., 2012. The team orienteering problem with time windows: An lp-based granular variable neighborhood search. European journal of operational research, 220(1), pp.15-27.

Lin, S.W. and Vincent, F.Y., 2012. A simulated annealing heuristic for the team orienteering problem with time windows. European Journal of Operational Research, 217(1), pp.94-107.

Lin, S.W. and Vincent, F.Y., 2017. Solving the team orienteering problem with time windows and mandatory visits by multi-start simulated annealing. Computers & Industrial Engineering, 114, pp.195-205.

Marzal, E. and Sebastia, L., 2022, September. Team orienteering problem with time windows and variable profit. In 2022 17th Conference on Computer Science and Intelligence Systems (FedCSIS) (pp. 347-350). IEEE.

Marzal, E. and Sebastia, L., 2024. Solving the tourist trip design problem with time windows and variable profit using incremental local search. Applied Soft Computing, 155, p.111399.

Righini G, Salani M. Dynamic programming for the orienteering problem with time windows. Technical Report 91 2006, Dipartimento di Tecnologie dell'Informazione, Universita degli Studi Milano, Crema, Italy.

Tsiligirides, T. (1984). Heuristic methods applied to orienteering. *Journal of the Operational Research Society*, *35*(9), 797-809.

Vansteenwegen, P., Souffriau, W., Vanden Berghe, G. and Van Oudheusden, D., 2009a. Iterated local search for the team orienteering problem with time windows. Computers & operations research, 36(12), pp.3281-3290.

Pieter Vansteenwegen, Wouter Souffriau, GreetVanden Berghe, and DirkVan Oudheusden. Metaheuristics for tourist trip planning. In Metaheuristics in the Service Industry, volume 624 of Lecture Notes in Economics and Mathematical Systems, pages 1531. Springer Berlin Heidelberg, 2009b.

Vincent, F.Y., Redi, A.P., Jewpanya, P. and Gunawan, A., 2019. Selective discrete particle swarm optimization for the team orienteering problem with time windows and partial scores. Computers & Industrial Engineering, 138, p.106084.

Vincent, F.Y., Jewpanya, P., Lin, S.W. and Redi, A.P., 2019. Team orienteering problem with time windows and time-dependent scores. *Computers & Industrial Engineering*, *127*, pp.213-224.