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Christian ARTIGUES[1], Emmanuel HEBRARD[1], Alain QUILLIOT[2], Peter J. STUCKEY[3*] & Hélène TOUSSAINT[2]

[1] LAAS-CNRS, Universite de Toulouse, CNRS, Toulouse, France
[2] LIMOS UCA/CNRS, Labex IMOBS3, Clermont-Ferrand, France
[3] FACULTY OF INFORMATION TECHNOLOGY, MONASH UNIVERSITY, Clayton VIC 3800, Australie

During the period 2016-2019, the H2020 GEOSAFE European project [1] has gathered both practitioners and academic researchers from the E.U. and Australia with the overall objective of developing methods and tools enabling authorities to organize an effective response to wildfire. In such circumstances, decisions which have to be taken are about fighting the cause of the disaster, adapting standard logistics (food, drinkable water, health…) to the current state of infrastructures, assigning and routing resources, and evacuating endangered areas (see [2, 3]). We focus here on the last kind of the decisions, and more specifically on what is called the *late evacuation problem*, that means the evacuation of people and eventually critical goods which have stayed at a place endangered by wildfire as long as possible.

While in practice evacuation planning is principally designed by experts, Operations Research and Computer Aided approaches have more recently addressed this problem [4]. In both cases, it is commonly admitted that planners work according to a 2-step process: the first step, which works as a pre-process, is a *routing* step devoted to the identification of the routes that evacuees are going to follow in order to go from their original location to an assigned shelter spot; the second step, which is a *scheduling* problem and has to be performed in real time in face of an evolving situation, is about the scheduling of the evacuation of estimated late evacuees along these pre-determined routes, while taking into account predictions about the availability of these routes. As a matter of fact, efficiently performing this second step means first forecasting the different possible scenarios for wildfire propagation, and next deciding about priority rules and evacuation rates imposed to evacuees when their respective routes share a same arc of the transit network (see [2, 4, 5]). While the forecasting issue is not going to be addressed here, one should be aware of its importance and difficulty, specifically in the specific case of wildfire, because of the dependence of wildfire expansion on changing winds, fuel load and terrain contours. It has to be handled through statistical management techniques [2, 3].

We address here the evacuation issue through its two main combinatorial optimization features, which means both its *scheduling* and *routing* side.

- The *scheduling* model which we use is close to the one proposed in [5] and called the *non preemptive evacuation planning problem* (NEPP). According to this model, estimated remaining evacuees have been previously clustered into groups, every group being characterized by its original location and its volume or population. For every such a group, evacuees follow a pre-computed route which makes them reach some safe area, and an assumption (*Non Preemption* hypothesis) is made that once the group has started moving along its assigned path, then it must keep on at the same rate until every member of the group could reach his target safe area. Though it looks rather restrictive from a mathematical point of view, this assumption matches practical concerns related to the difficulty to impose any change on evacuees (e.g. interruption, speed or rate change) during the evacuation process. But while this model is addressed in [5, 4] through constraint propagation and discretization of both the time space and the rate domains, we consider it as an extension of the well-known *Resource Constrained Project Scheduling Problem* (RCPSP). This extension involves continuous variables related to evacuation rates, an objective function which is not the traditional *makespan* but a safety measure and an emerging concept which we call *conditional time lags*. We first design and implement several feasibility checking procedures, related to the case when some bottlenecks arcs exist in the transit network and when the network is a tree. Next we design and test a heuristic algorithm which deals with our problem according to network flow like techniques while relying on our RCPSP framework. This approach yields a fast algorithm and is well-fitted to real-time emergency contexts.

- We address the *routing* issue through a formulation of the problem as a network flow model defined on a *time expanded network,* inspired by previous work [6]. This framework allows us both to maintain and keep on with the *non preemption* hypothesis, while putting some flexibility on the way population are clustered into evacuee groups, and setting the search for efficient evacuation routes at the core of the model. Since the size of such a network tends to increase excessively fast, we handle it in an implicit way, while adapting standard network flow algorithms (*min cost*, *max flow*) to the case when flow vectors take their values inside piecewise constant and piecewise linear functional spaces. Algorithms which we propose and implement here may be turned, depending on the context, into both exact and heuristic algorithms, and they may also be used in order to get accurate optimistic estimation for the scheduling models.

Applications of the research for fire and landscape management

As explained in the introduction, the whole research which is presented here is motivated by fire and landscape management and more precisely by the late evacuee issue.

Few References.

[1]. Geo-Safe- geospatial based environment for optimization systems addressing fire emergencies; *MSCA-RISE 2015 European Project –id 691161*. http://fseg.gre.ac.uk/fire/geo-safe.html. (2018).

[2]. V.Bayram : Optimization models for large scale network evacuation planning and management : a littérature review ; *Surveys in Operations Research and Management Sciences*, (2016), DOI : 10.1016/j.sorms.2016.11.001.

[3]. S.Shahparvari, P.Chhetri, B.Abbasi and A.Abareshi: Enhancing emergency evacuation response of late evacuees: revisiting the case of Australian black Saturday bushfire; *Transportation Research Part E: Logistics and Transportation*, 93, p 148-176, (2016).

[4]. C.Even, V.Pillac, P.Van Hentenryk: Convergent plans for large scale evacuation; In *Proc. 29 th AAAI Conf. On Artificial Intelligence*, Austin, Texas, p 1121-1127, (2015).

[5]. C.Artigues, E.Hebrard, Y.Pencolé, A.Schutt, P.Stuckey: A study of evacuation planning for wildfires; *17 th Int. Workshop on Constraint Modelling and Reformulation (ModRef 2018)*, Lille, France, (2018).

[6]. A.Quilliot, H.Toussaint: Flow Polyedra and Resource Constrained Scheduling Problem, *RAIRO-RO*, 46-04, p 379-409, (2012).