# Valid inequalities for dynamic asset protection during escaped wildfires

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## 1 Introduction

In the recent years, wildfires around the world have become more frequent and more damaging. During these wildfires, community assets such as schools, hospitals, bridges, or factories, face the risk of being damaged or destroyed. In some cases, this risk can be diminished or nullified if preventive protection actions are taken. Protection requires resources to be dispatched in a timely manner to the asset. These interventions are carried out by the Incident Management Teams (IMT) before the fire reaches the assets. Such actions include removing fuel materials, wetting down buildings, or reducing fire. The time window for performing these actions is crucial : they have to be taken before the fire fronts reach the asset, but not too early for the protection to be efficient. Some interventions may require several trucks with specific capacities, thus requiring different teams to collaborate to perform the task in a synchronous way.

Based on fire spread and behavior models, it is possible to plan routes for each of the trucks respecting the synchronization and time windows constraints, so that a maximum number of community assets are protected. However, unforeseen disruptions, such as changes in weather, vehicle breakdowns, or road closures, may happen. It is then crucial to update the initial plans and reallocate the resources in response to these unexpected changes. This problem is known as the dynamic Asset Protection Problem (APP).

## 2 Contribution

A mixed integer program (MIP) for the dynamic APP was proposed by Van der Merwe *et al.* [3]. It is modeled as a bi-objective Synchronized Team Orienteering Problem with Time Windows (STOPTW), where the objectives are to maximize the total protected value while minimizing the deviation from the pre-disruption assignments. The MIP was used within an $\epsilon$-constraint scheme [1] to generate the full Pareto front. The set of non-dominated points is generated iteratively, by limiting the secondary objective (here, the deviation) to a certain value $\epsilon$. At each step, the value of $\epsilon$ is decreased to generate a new non-dominated point.

We studied the structure of the dynamic APP and the MIP formulation to deduce efficient valid inequalities. In the following, we present two sets of valid inequalities based on lower bounds of the deviation for the protection of an asset, and two sets based on cliques.

First, we considered $nb_v$, the minimal number of vehicles required for the protection of an asset. We can compute this value for each asset by solving a MIP that can be interpreted as a multidimensional knapsack problem. Despite the NP-hardness of the problem, we can efficiently solve the MIP due to its small size.

We introduced two different sets of valid inequalities that use $nb_v$ :

— Addition cuts : when an asset is protected in a solution, the asset has been added to the route of at least $nb_v$ vehicles.
— Total deviation cut : the sum of $nb_v$ for all the protected assets is less than the value of $\epsilon$, the maximum authorized deviation.

Time constraints on the assets can make it impossible for a vehicle to visit consecutively two assets within their time windows. Such pair of assets are called incompatible/vehicle.

We introduced two different sets of valid inequalities that use cliques of the graph of incompatible/vehicle assets :

— Incompatibility/vehicle clique cuts : only one asset of the clique can be visited by a distinct vehicle.
— Incompatibility/solution cuts : if the available vehicles are not sufficient for the protection of every asset in the clique (with every vehicle assigned to at most one asset), then at least one of the assets of the clique is not protected.

# 3 Results

We generated the extreme point allowing for maximum deviation, with three different randomly selected vehicle breakdowns as the disruption, for 10 instances.

The valid inequalities we proposed greatly improved the resolution of the model. For instances with 60 assets, the model alone could only solve 4 instances out of 30 within the time limit of 1800 seconds. When adding the incompatibility/vehicle clique cuts to the MIP, we were able to solve 5 additional instances, and up to 11 out of 30 instances with all the cuts. On average, adding the incompatibility/vehicle cuts reduced the solve time of the 4 instances solved by the initial model from 458 to 309 seconds. Adding all the cuts halved the solve time down to 418 seconds for the 9 instances solved by the model with incompatibility/vehicle cuts only.

We noted that addition cuts alone did not impact the solve time, but greatly improved the linear relaxation of the model. That could explain why, when we coupled them with the incompatibility/vehicle clique cuts, we further speed up the resolution.

# 4 Conclusion

We studied our problem to extract valid inequalities that allowed us to solve more instances to optimality. However, the resolution time for the extreme point is still too high to use this model for generating the full Pareto front in reasonable time. Exact resolution for the dynamic APP would require a deep change in the formulation or the resolution method to be efficient.

### Acknowledgements

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# Références

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