

Short contribution – Fire Management

Flexible design of a helipad network for forest firefighting helicopters, applied to the case of Sardinia

Hugo Torres¹, Abílio Pereira Pacheco^{2*}, João Claro³, Michele Salis², Matthew P. Thompson³, Crystal S. Stonesifer³, Gavino Diana⁴, Silvio Cocco⁴

¹ INESC TEC. Campus da FEUP, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal, {hugo.torres@fe.up.pt; app@fe.up.pt*, jclaro@fe.up.pt}.

² National Research Council, Institute of Biometeorologia. Traversa La Crucca n.3, Sassari (Italy); Euro-Mediterranean Center on Climate Change Foundation, IAFES Division of Sassari. via de Nicola 9, Sassari (Italy), {miksalis@ibimet.cnr.it}.

³ Rocky Mountain Research Station, USDA Forest Service. Missoula, MT 59801, USA, {mpthompson02@fs.fed.us., csstonesifer@fs.fed.us}.

⁴ Sardinia Forest Service. Via Umberto I° 414, Jerzu, Italy, {gdiana@regione.sardegna.it, scocco@regione.sardegna.it}

Abstract

Cost-effective strategic management of aerial forest fire suppression resources involves decisions about fleet location, in order to efficiently match supply and demand. In this study, we explore the flexible design of such a system, pooling the demand of several bases into a “zone”, and analyzing alternative partitions of the territory into zones. Feasible partitions consider an upper limit on the distance between bases, and require their adjacency, within the same zone. Then, we classify the feasible partitions according to a set of six criteria and explore the non-dominated partitions. Finally, we select the preferred partition, with the support of several experts, by applying the AHP method. The considered criteria evaluate, for each partition, the (c1) mean and the (c2) value at risk of the number of unattended active fires, the (c3) helicopter idleness, and the (c4-6) Gini index for each of the previous three criteria.

We apply this strategy to the island of Sardinia, where helicopters play a central role in the suppression system, and compare the results with the current design, in which each base is autonomous (i.e., each zone has only one base). Sardinia has eleven helipad operational bases, where the helicopters are allocated at the beginning of the fire season, with the objective of fighting wildfires located in each base’s coverage area. We used fire occurrence and helicopter flight data from 2006 to 2010, which revealed spatiotemporal asymmetries in the forest fire patterns, along the island, and thus the existence of effective opportunities to benefit from demand pooling. The AHP method was applied with Portuguese experts, and our results point towards an improvement in the values related to unattended fires, as well as the Gini indexes, if the proposed strategy of reorganizing the territory in larger zones (with more than one base) is applied.

We explore the results of our approach, and identify efficiency gains, potential fire management implications, limitations, and opportunities for additional research. In the scope of the latter, as the optimal value for helicopter idleness is naturally achieved with the current design (partition in zones with one base), this criterion provides a key trade-off with the other five, that can be used, for instance, to examine a flexible strategy for helicopter location-allocation along the years, with annual partition redefinitions, considering all data available up to that point of decision.

Keywords: helicopter basing, flexibility, territory partition, partitions, cost-effective analysis, AHP, decision factors

1. Introduction

Cost-effective strategic management of aerial forest fire suppression resources involves decisions about fleet location, in order to efficiently match supply and demand. Sardinia currently has eleven

operational helicopter bases, where helicopters are allocated at the beginning of the fire season, to fight the fires located in each base's coverage area. Our goal was to optimize the usage of fire-fighting helicopters, creating a dynamic and flexible designed system for helicopter management, as opposed to the current system, a fixed design where the helicopters are allocated to each base and remain attached to the base for the whole season of fires.

The new flexible design consists in a system of partitions, where the coverage of each area can be shared with other bases, which leads to a narrower gap between the level of service and the demand of the helicopters. This work comes as the sequence of the previous work of Pacheco *et al.* (2014), later adapted to Sardinia by Stonesifer *et al.* (2015).

The results – first presented in Torres *et al.* (2017) – point towards an improvement in the values related to unattended fires, as well as the Gini indexes, and departing from the optimal value for helicopter idleness naturally achieved with the current configuration, this being the key trade-off that should be explored in order to find a solution that balances the multiple requirements.

5. Materials and Methods

Sardinia island is a territory belonging to Italy, situated on the Mediterranean Sea, west of the Italian mainland with approximately 1.7M inhabitants (Salis *et al.* 2013) and an area of approximately 24,000Km² (Bajocco and Ricotta 2008) consisting mostly on shrublands (28% of the islands' area).

In this study, we explore the flexible design of such a system, pooling the demand of several bases into a “zone”, and analyzing alternative partitions of the territory into zones. Feasible partitions consider an upper limit on the distance between bases, and require their adjacency, within the same zone (please see Figure 1).

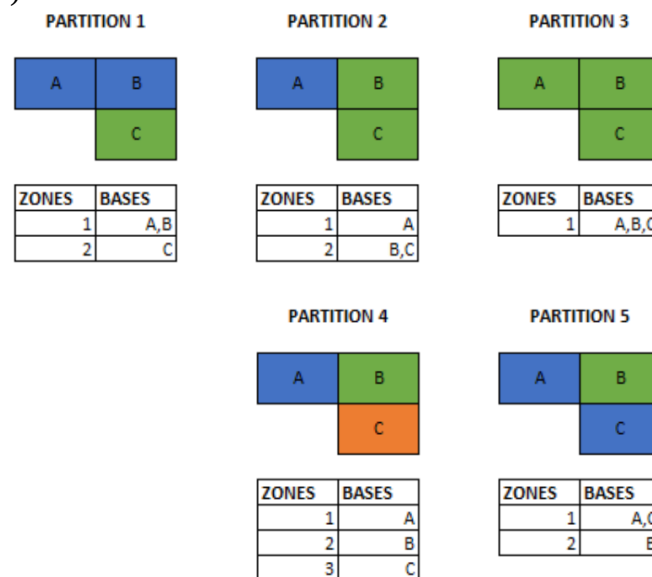


Figure 1 - An example with a territory with 3 bases (A, B, and C); there are five possible partitions: four partitions are viable (#1-4), and one partition is not viable (#5) as in the “blue” zone 1, bases A and C, are not adjacent.

To evaluate the adjacency of bases, we build a matrix in which the position (i,j) is 1 if the bases i and j are adjacent, and 0 if not. This matrix is then subset when we evaluate the adjacency of the bases within a zone. It is important to notice that this method also represents a different restriction in this scenario. Since some of the bases are equipped to a specific type of helicopter, they cannot be included in zones where there are other types of helicopters. Given this, the adjacency matrix can indicate that two bases are not adjacent if they are not prepared for the same type of helicopters, even though they are geographically adjacent.

After evaluating adjacency and distance, we classify the feasible partitions according to a set of six criteria and explore the non-dominated partitions. Finally, we select the preferred partition, with the support of several experts, by applying the AHP method. The considered criteria evaluate, for each partition, the (c1) mean and the (c2) value at risk of the number of unattended active fires, the (c3) helicopter idleness, and the (c4-6) Gini index for each of the previous three criteria.

We apply this strategy to the island of Sardinia, where helicopters play a central role in the suppression system, and compare the results with the current design, in which each base is autonomous (i.e., each zone has only one base). Sardinia has eleven helipad operational bases, where the helicopters are allocated at the beginning of the fire season, with the objective of fighting wildfires located in each base's coverage area. We used fire occurrence and helicopter flight data from 2006 to 2010, which revealed spatiotemporal asymmetries in the forest fire patterns, along the island, and thus the existence of effective opportunities to benefit from demand pooling.

The AHP method was applied with experts from the Portuguese authorities related to fire, suppression such as the National Authority for Civil Protection (ANPC) or the National Institute for Forest Conservation (ICNF), and our results point towards an improvement in the values related to unattended fires, as well as the Gini indexes, if the proposed strategy of reorganizing the territory in larger zones (with more than one base) is applied.

2. Results

We explore the results of our approach (please see Figure 2), and identify efficiency gains, potential fire management implications, limitations, and opportunities for additional research.

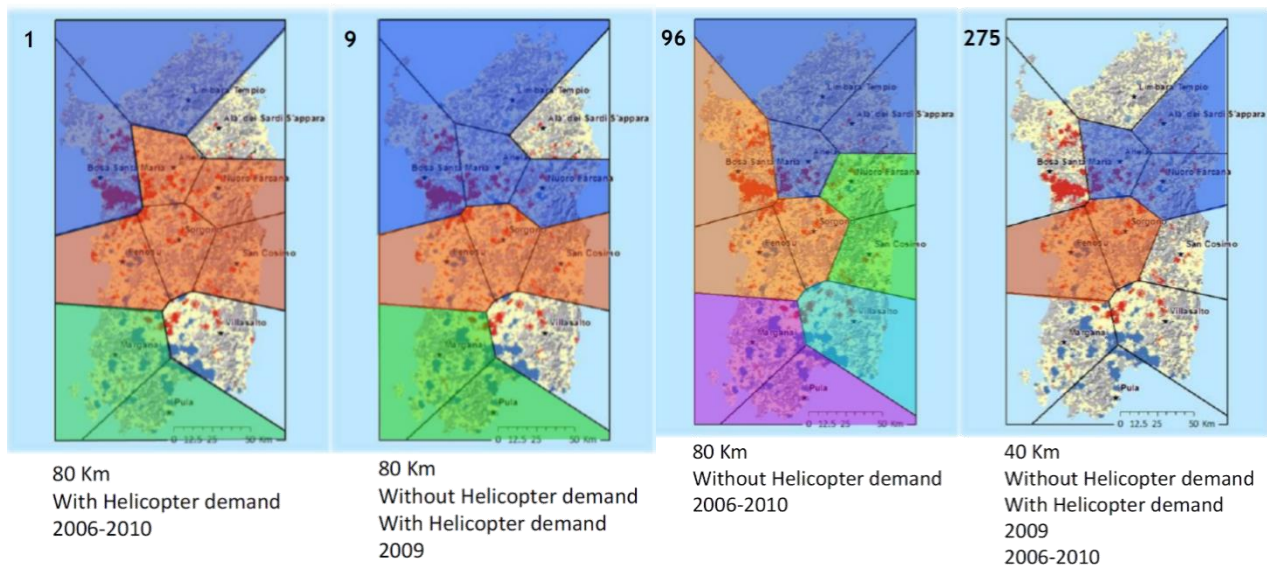


Figure 2 - Territory partitions chosen by the AHP analysis for a threshold of 80Km considering the demand probability (each color represents a zone).

In the scope of the latter, as the optimal value for helicopter idleness (c3) is naturally achieved with the current design (partition in zones with one base), this criterion provides a key trade-off with the other five, that can be used, for instance, to examine a flexible strategy for helicopter location-allocation along the years, with annual partition redefinitions, considering all data available up to that point of decision.

3. Conclusion

The results seem to indicate that pooling the demand of the system may lead to an improvement of the efficiency, favoring the flexible design over the fixed design. However, we believe that there is

room for improvement for this algorithm. The trade-off between the helicopter idleness and the other criteria, along with the possibility of relating fires and flights and using a broader time interval, seem to be some interesting starting points for future development of this design.

4. Acknowledgements

This work is financed by the ERDF – European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation – COMPETE 2020 Programme within project «POCI-01-0145-FEDER-006961», and by National Funds through the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) as part of project UID/EEA/50014/2013. FCT also supported the research performed by Abílio Pereira Pacheco (Grant SFRH/BD/92602/2013).

The authors are deeply grateful to Eng.º Rui Almeida (ICNF) and Professor Richard de Neufville (MIT, IDSS) for their enthusiasm and advice. We also thank Tenente-Coronel Albino Fernando Quaresma (GIPS), Comandante Marco Martins (B.V. de Óbidos), Doutor João Carlos Verde, Eng.º Paulo Mateus (ICNF), Dr. Alexandre Benigno (ANPC), and Eng.º Paulo Bessa (GTF Penafiel) for answering the survey used to apply the AHP model.

5. References

- Bajocco, S, Ricotta, C (2008) Evidence of selective burning in Sardinia (Italy): which land-cover classes do wildfires prefer? *Landscape Ecology* **23**, 241-248.
- Pacheco, AP, Neufville, Rd, Claro, J, Fornés, H (2014) Flexible design of a cost-effective network of fire stations, considering uncertainty in the geographic distribution and intensity of escaped fires. In 'Advances in forest fire research'. (Imprensa da Universidade de Coimbra: Coimbra)
- Salis, M, Ager, AA, Arca, B, Finney, MA, Bacciu, V, Duce, P, Spano, D (2013) Assessing exposure of human and ecological values to wildfire in Sardinia, Italy. *International Journal of Wildland Fire* **22**, 549-565.
- Stonesifer, C, Thompson, M, Salis, M, Pacheco, AP, Claro, J CMCC (Ed.) (2015) Flexible Design of Helicopter Basing Strategies: A Case Study of Sardinia, Italy, 'International Conference on Fire Behaviour and Risk'. Alghero, Italy.
- Torres, HS, Pacheco, AP, Claro, J, Salis, M, Thompson, MP, Stonesifer, CS, Diana, G, Cocco, S (2017) Flexible design of a network of helipads for a fleet of forest firefighting helicopters, 2017 'World Conference on Natural Resource Modeling: Vulnerability and Resilience of Socio-ecological Systems'. Barcelona, Spain, June 6-9, 2017. Available at http://www.paucostafoundation.org/nrm2017/wp-content/uploads/2017/06/wcnrm2017_program_doublepage.pdf