

The Wildfire Risk Management System of Portugal: Using Decision Rules in a Simulation Model to Minimize Total Costs

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Presentation Outline

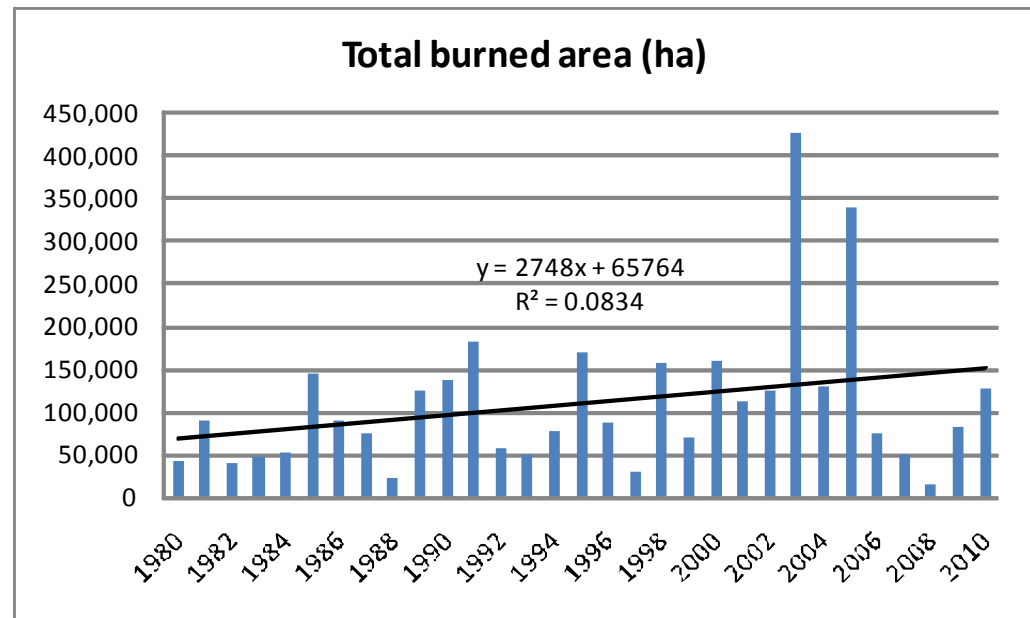
- Problem Overview
- Defining the System
- Defining the Uncertainties
- Designing the System
 - Fixed
 - Flexible
- Optimality under Fixed Design
- Evaluation of Flexible Designs
- Conclusions

Problem Overview

- Wildfire is a serious national problem in Portugal
- Number of ignitions, hectares burned, and damages to ecosystem and property all increasing [1,2,3]
- Extensive burned areas from 2003 and 2005 now ready to burn again [1]



Record 1,000 new fires registered over single weekend in early August this year [4]

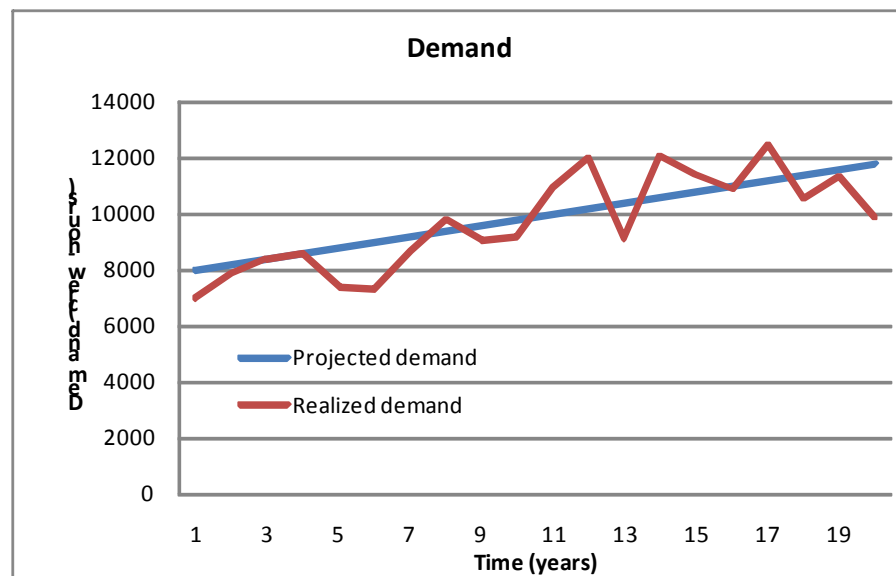


Defining the System

- Discrete unit of capacity: Portuguese firefighting “crews”
 - Includes personnel (handcrew, hotshots, smokejumpers, rappellers), equipment and vehicles (fire retardants, plows, engines, helicopters)
 - True firefighting capacity unknown → crew not defined explicitly
 - Initial capacity assumed to be 4 crews (arbitrary)
- Demand: yearly crew-hours of labor required to fully suppress all fires during the fire season
 - Crew-hours of labor not met by supply capacity result in expensive losses due to escaped fire damages
 - 20-year planning horizon

Defining the Uncertainties

- Major uncertainty in wildfire risk management is the behavior (ignitions, spread, effects) of all fire that occurs
- Demand for crew-hours of firefighting labor is a crude proxy for this uncertainty
 - Assumes gradual inter-year increase due to factors associated with global climate change [1]
 - Assumes 20% variability around yearly demand projection



Note: demand projections not data-driven, they are made up

Designing the System (1 of 2)

- Fixed Designs:
 - *Unconstrained Budget* – assumes Portuguese gov't has sufficient funds to train and deploy the optimal* number of Portuguese crews over the initial capacity (4)
 - *Constrained Budget* – assumes gov't cannot (or will not) spend any money on crews above current capacity (business as usual)
- Flexible Designs:
 - *Contract Out* – allows foreign firefighting crews to be contracted (at a premium) to meet demand
 - *Expand* – allows expansion of Portuguese firefighting capacity by one crew after seasons when demand exceeded supply
 - *Do Both* – combined approach that allows both options

* Derived by minimizing NPV of total costs over 20-year planning horizon

Designing the System (2 of 2)

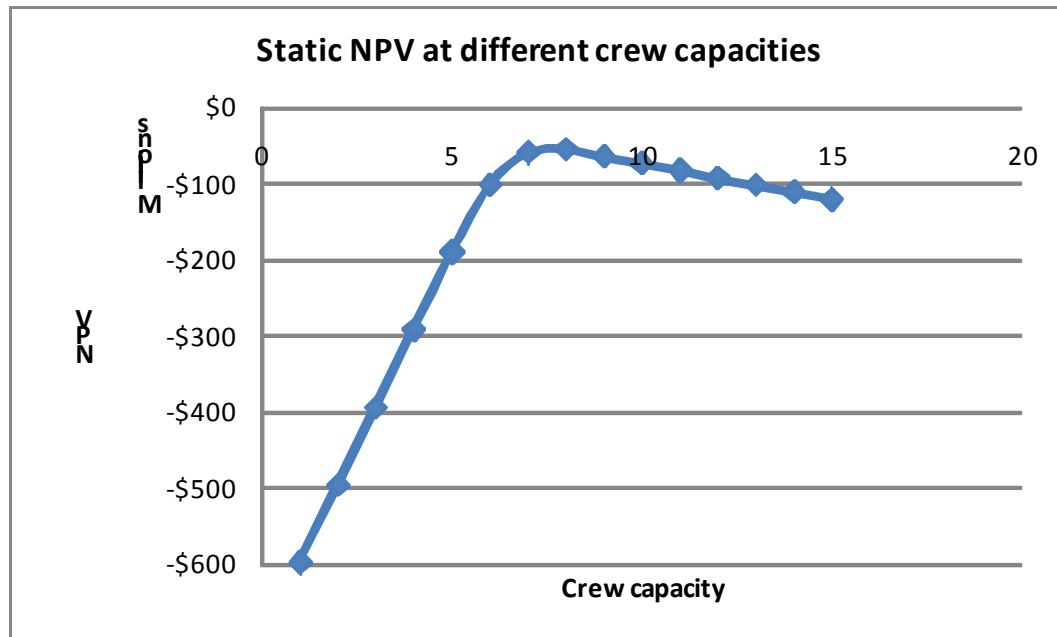
- Objective function is to minimize NPV of total costs over 20-year planning horizon
 - Per hour operating costs
 - Costs of escaped fire (crew-hours of demand not met)
 - Fixed costs of training and deploying new crews

3	Demand projections		
4	Demand in year 1	8000	crew-hours
5			
6	UNCERTAINTY ASSUMPTIONS		
7	Realised demand each year within	20%	of demand projection
8			
9	Average operating costs	\$200	per crew-hour (wages, equipment, etc.)
10	Average cost of escaped fire	\$5,000	per crew-hour (demand not met)
11	Fixed costs per crew (above 4)	\$5,000,000	per crew (training, facilities, etc.)
12	Fixed costs (total)	\$20,000,000	
13			
14	Capacity limit	1500	hours per crew
15	Initial capacity	4	crews
16	Optimal capacity	8	crews
17			
18	Time horizon	20	years
19	Discount rate	3%	

There are no revenue streams generated from suppressing fire in the model.

Note: system parameters are made up

Fixed Design with Unconstrained Budget



Crew capacity	ENPV
5	-\$193,278,978
6	-\$114,621,282
7	-\$72,416,823
8	-\$61,084,294
9	-\$65,357,136
10	-\$74,632,425

8 crews still optimal under uncertainty

Under 8 crews, NPV is approx. -\$56 million

18	Year							
19	Demand	10600	10800	11000	11200	11400	11600	11800
20	Capacity	12000	12000	12000	12000	12000	12000	12000
21	Revenue	\$0	\$0	\$0	\$0	\$0	\$0	\$0
22	Operating costs	\$2,400,000	\$2,400,000	\$2,400,000	\$2,400,000	\$2,400,000	\$2,400,000	\$2,400,000
23	Escaped fire costs	\$0	\$0	\$0	\$0	\$0	\$0	\$0
24	Fixed costs	\$0	\$0	\$0	\$0	\$0	\$0	\$0
25	Cashflow	-\$2,400,000	-\$2,400,000	-\$2,400,000	-\$2,400,000	-\$2,400,000	-\$2,400,000	-\$2,400,000
26	DCF	-\$1,586,683	-\$1,540,469	-\$1,495,601	-\$1,452,039	-\$1,409,747	-\$1,368,686	-\$1,328,822

Capacity always stays above demand!

Shape of curve above representative of discrepancy between operating costs (\$200 per crew-hour) and escaped fire costs (\$5,000 per crew-hour demand not met)

Modeling the System with Simulation

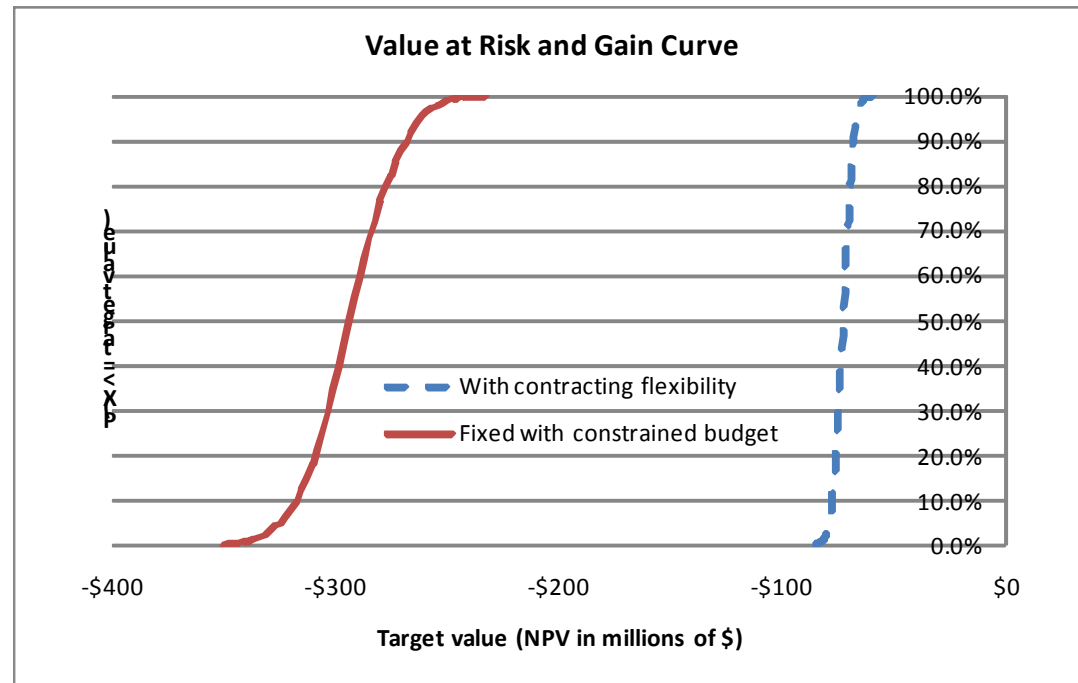
- Flexible designs built on top of the fixed design with *constrained* budget (business as usual)
 - ENPV of fixed unconstrained: approx. -\$61 million (8 crews)
 - ENPV of fixed constrained: approx -\$293 million (4 crews)
- Flexible Design 1: Contract Out
 - \$1,000 per crew-hour of foreign firefighting labor
- Flexible Design 2: Expand
 - \$5 million per new crew trained and deployed
- Flexible Design 3: Do Both
 - Both costs are incurred when options are exercised

Iterations	Mean	Max	Min	STD
2,000	-\$61,004,184	-\$55,705,940	-\$74,583,608	\$3,569,186
5,000	-\$60,943,208	-\$55,705,940	-\$74,134,012	\$3,443,240
10,000	-\$60,956,476	-\$55,705,940	-\$78,120,302	\$3,469,020



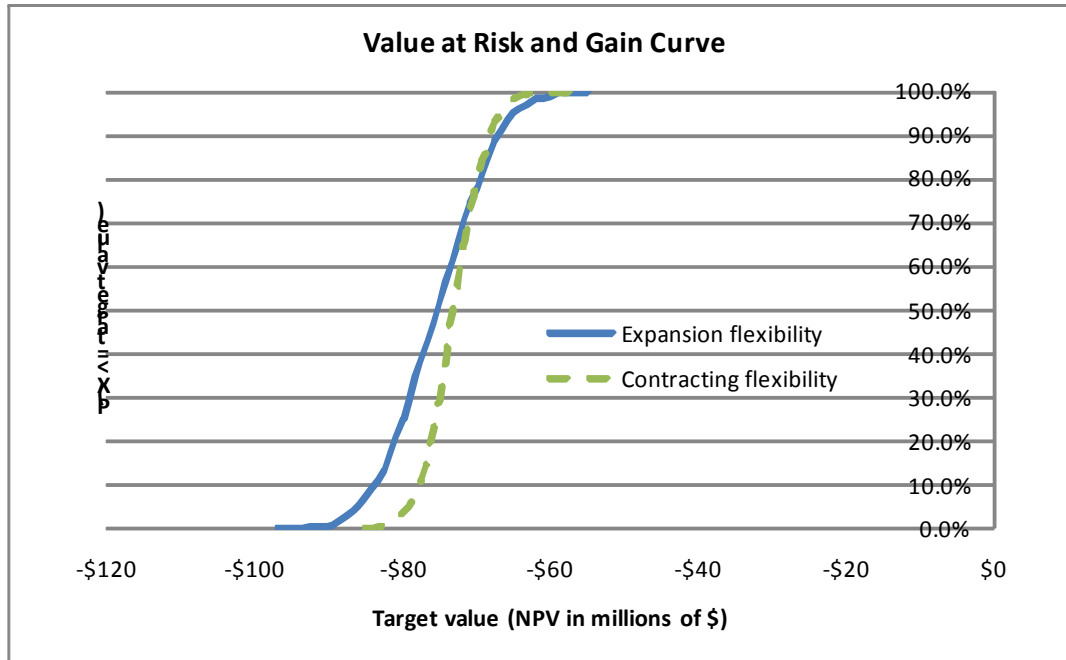
Statistics stable across simulation size (# of iterations) so 2,000 was deemed sufficient across designs

Flexible Design 1: Contract Out



- Discrepancy in magnitude makes sense; surplus demand now costs \$1,000 per crew-hour instead of \$5,000

Flexible Design 2: Expand

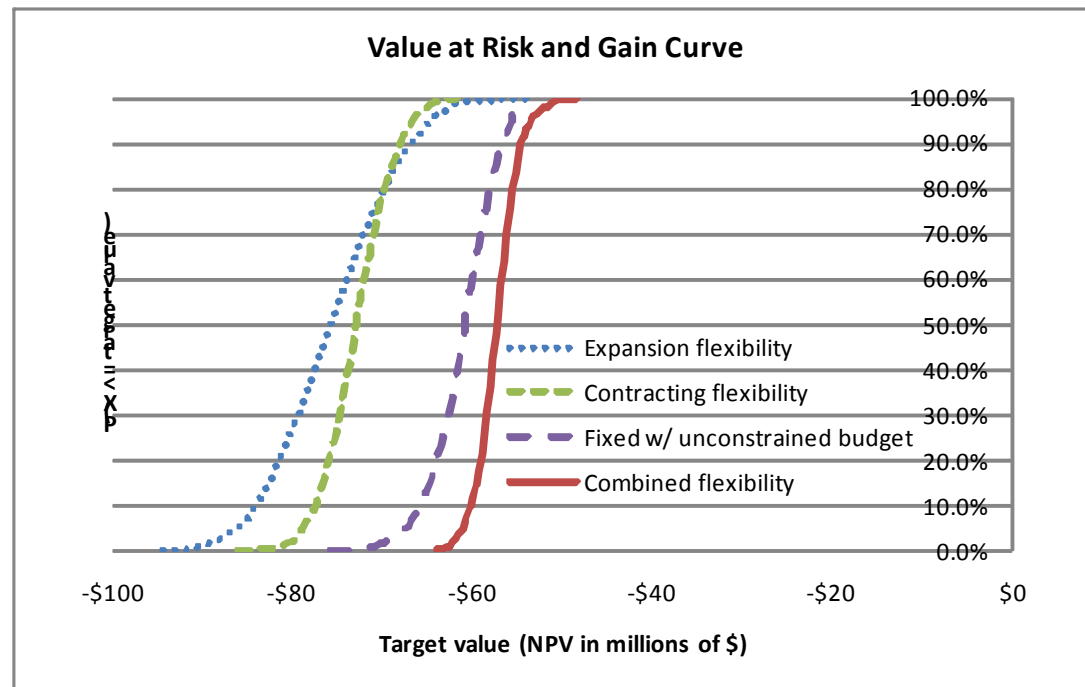


- Neither option is stochastically dominant
- Tradeoffs across the two options
- Fixed design with unconstrained budget still superior

Statistics	Expand	Contract Out	Fixed Unconstrained
Maximum	-\$55,265,188	-\$60,313,298	-\$55,705,940
P95	-\$64,425,672	-\$66,894,288	-\$55,705,940
Mean	-\$75,287,684	-\$72,869,606	-\$60,850,949
P5	-\$85,971,069	-\$79,019,172	-\$66,998,461
Minimum	-\$94,041,753	-\$85,484,768	-\$74,726,409



Fixed Design 3: Do Both



- Interaction between the two individual flexibilities leads to nonlinear gains in system performance with the combined approach
 - Stochastically dominates the budget-unconstrained fixed design

Conclusions

- Nonlinear gains in complex and uncertain engineering systems can be exploited through flexible design
 - Shown by modeling the wildfire risk management system of Portugal
- Combined flexible approach has better overall system performance than the fixed design with unconstrained budget *and* it does not require large upfront investment in new crews at the beginning of the planning horizon
 - At end of 20 years, there are still (usually) 8 crews in operation, but they are deployed in stages and supplemented by foreign firefighting aid when needed
- Limitations in current model due to heavy reliance on assumptions; future work could:
 - Produce more accurate cost parameters
 - Develop functional relationship between crew-hours demanded and yearly predicted ignitions, fire extents, and effects

References

- [1] Beighley, M. (2009, June). *Forest Defense against Fire in Portugal: Situation and Capability*. Beighley Consulting LLC.
- [2] Beighley, M., & Quesinberry, M. (2004). *USA-Portugal Wildland Fire Technical Exchange Project*. USDA Forest Service.
- [3] Oliveira, T. (2010). *Totais Distrito (1980-2010)*. Portugal: Ministério da Agricultura.
- [4] No Author (2010, August 12). Deadly fires rage on in Portugal. *BBC*. Retrieved from <http://www.bbc.co.uk/news/world-europe-10949997>