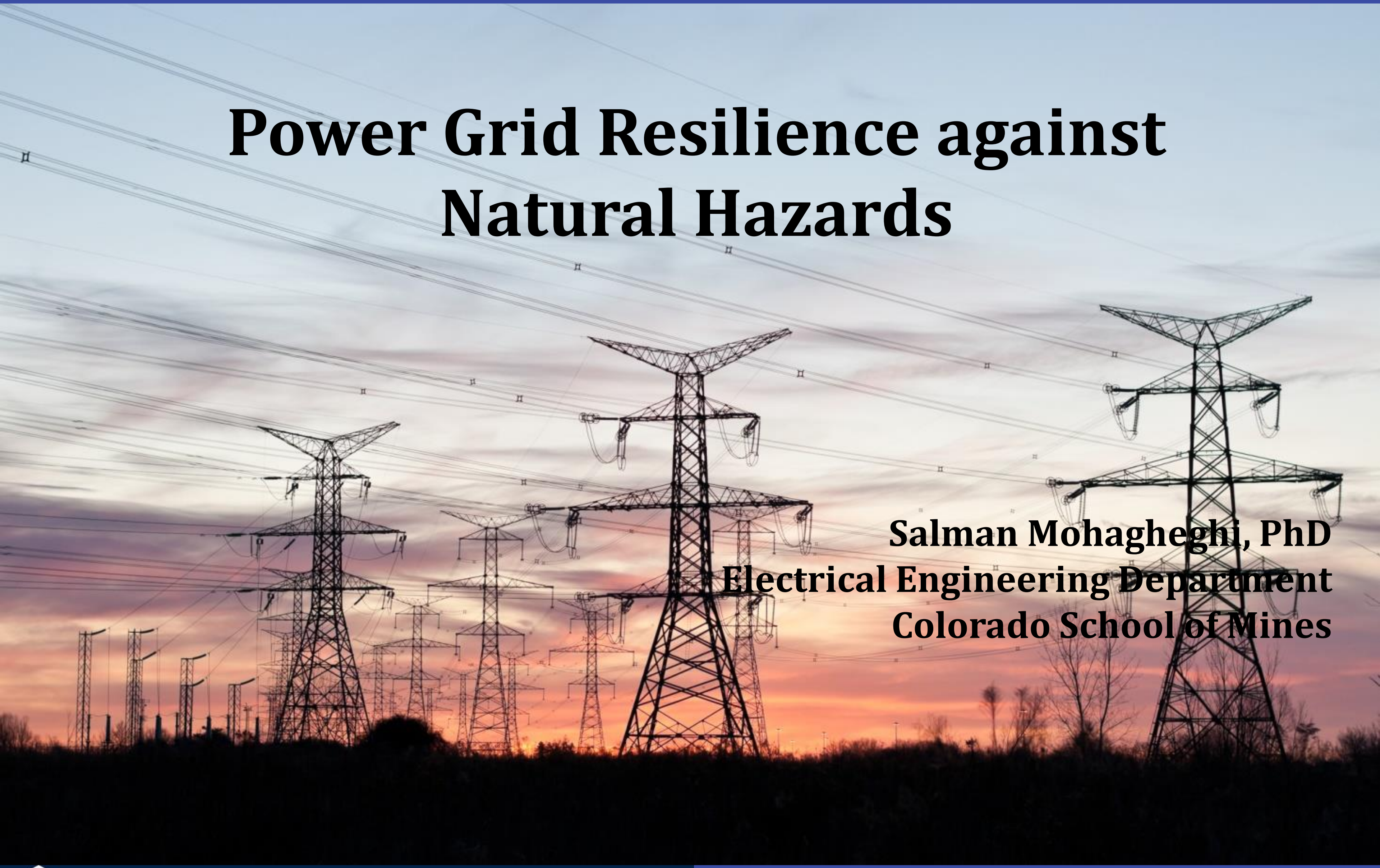
Power Grid Resilience against Natural Hazards



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Power Grid and Natural Disasters

- Natural disasters are the second biggest cause of large-scale outages in the US
- **Where is the Challenge?**
  - Uncertainties about the event, its spatial (and sometimes temporal) scope, its severity and its consequences
  - Assets are likely to be already operating close to their designed limits
  - In the case of weather-induced hazards, renewable energy resources are affected more
  - Traditional view of critical versus non-critical loads is not appropriate anymore

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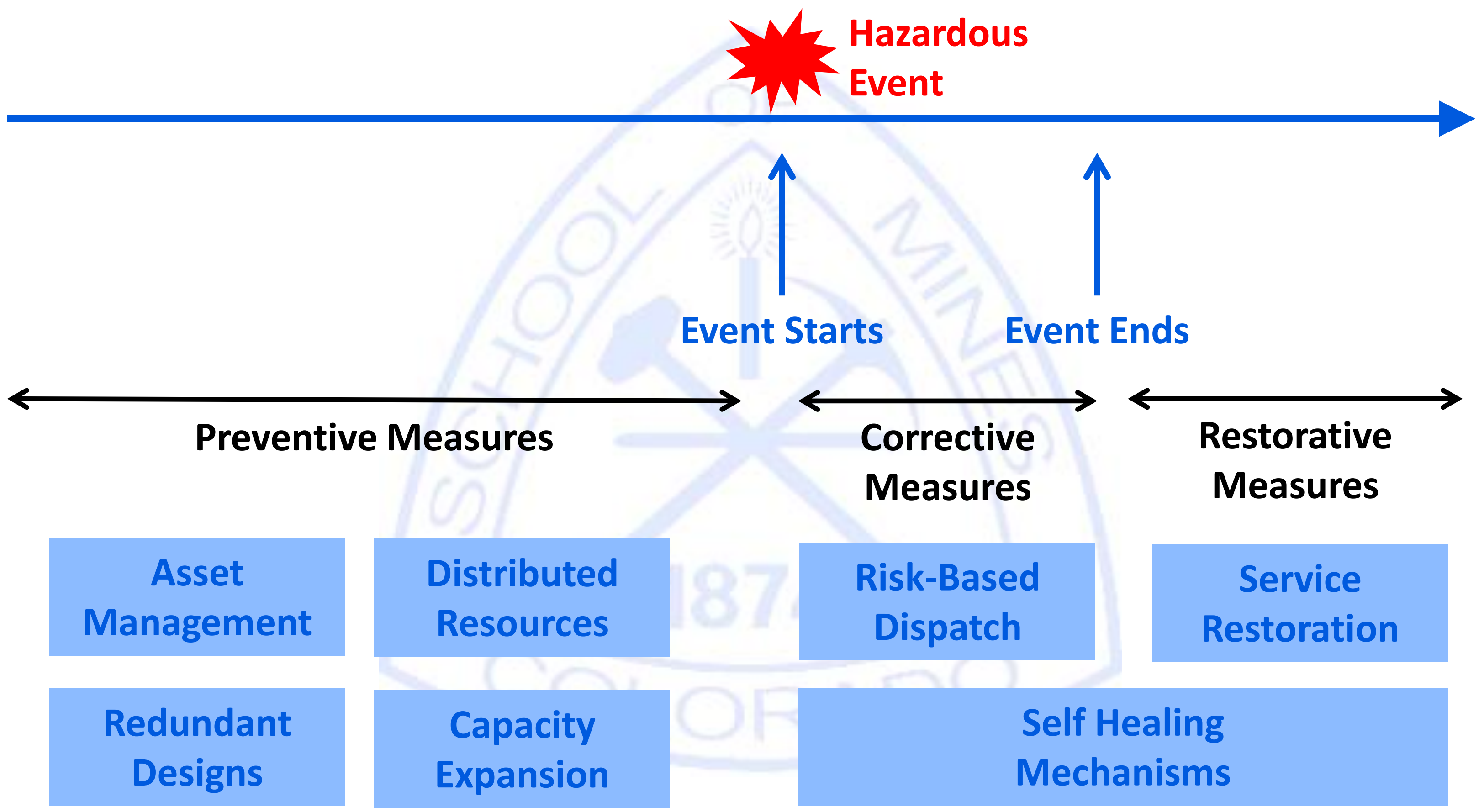
Power Grid and Natural Disasters

- What Can Be Done?



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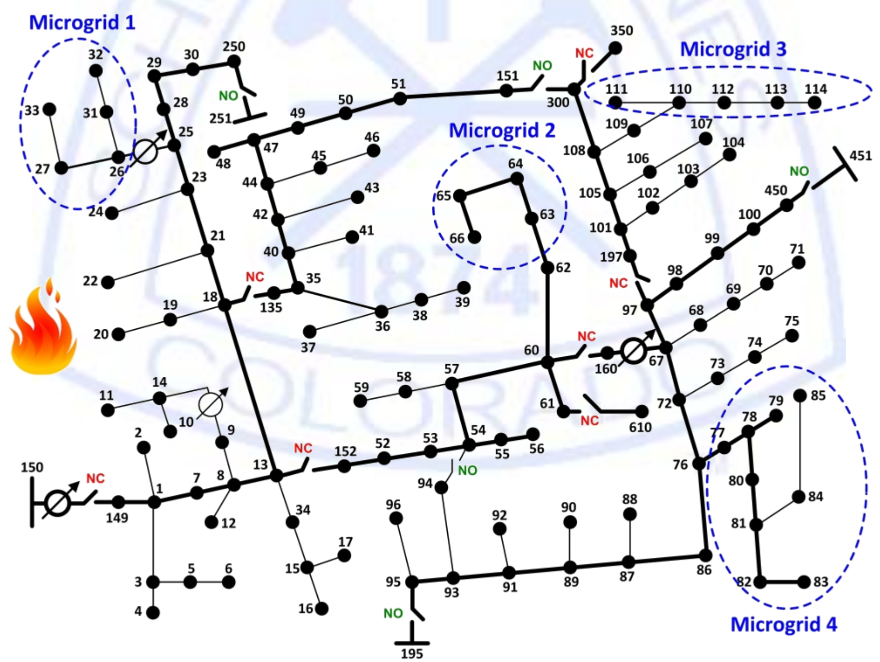
Power Grid and Natural Disasters

- **Case Study:** **A wildfire is approaching the power distribution system**
- **Objective:** **Find the most economical energy for dispatch of DER, DR and Microgrid resources that minimizes the probability of lost load**
- **Approach:** **2-stage stochastic optimization: purchase reserves before the onset of the event based on its expected impact, and dispatch them during the course of the event**



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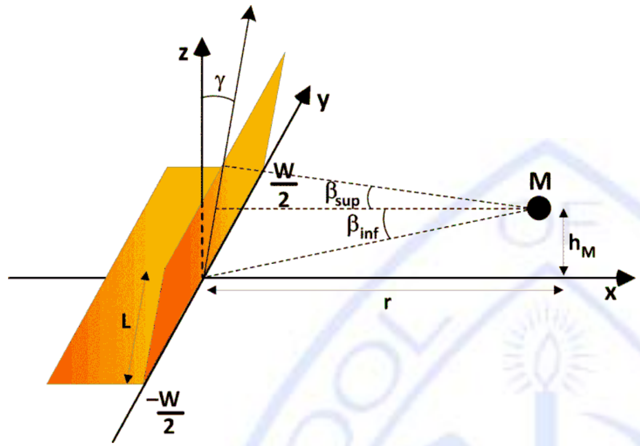
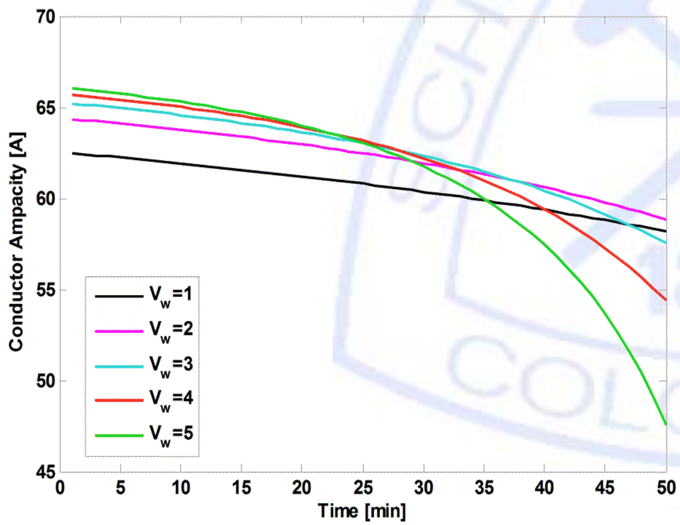
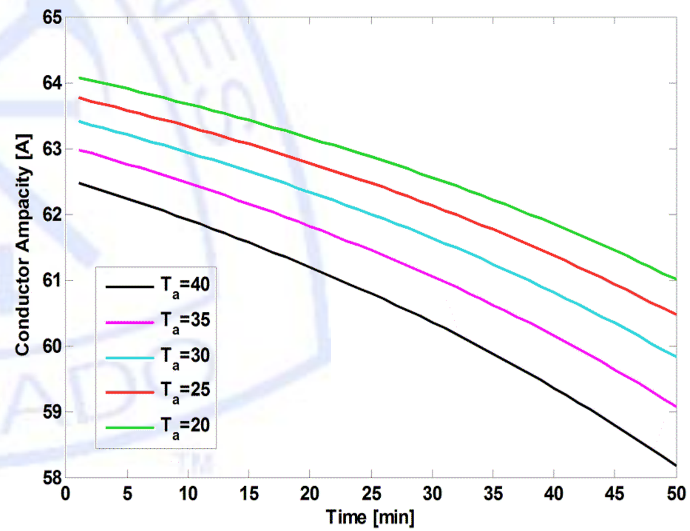


$$R \cdot I_{C,f}^2 + Q_s + Q_{r,f} = Q_r + Q_c$$

$$\Rightarrow I_{C,f} = \sqrt{\frac{Q_r + Q_c - Q_s - Q_{r,f}}{R}}$$





Variation in conductor ampacity based on different ambient temperatures and different wind speeds. For more information see: M. Choobineh, B. Ansari and S. Mohagheghi, "Vulnerability Assessment of the Power Grid against Progressing Wildfires," ***Fire Safety Journal*****, vol. 73, pp. 20–28, April 2015.**

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Power Grid and Natural Disasters

- **Problem Formulation:**

$$\min \begin{cases} \sum_{t\in T}\sum_{m\in M}\left(\sum_{g\in G_m} c^{res}_{m,g,t}\cdot P^{res}_{m,g,t} + \sum_{d\in D_m} c^{res}_{m,d,t}\cdot P^{res}_{m,d,t}\right) + \\ \sum_{s\in S} p_s \sum_{t\in T} c^{sub}_t \cdot P^{sub}_{t,s} + \\ \sum_{s\in S} p_s \sum_{t\in T}\sum_{m\in M}\left\{ u_{m,t,s}\cdot\left(\sum_{g\in G_m} c^{gen}_{m,g,t}\cdot P^{gen}_{m,g,t,s} + \sum_{d\in D_m} c^{DR}_{m,d,t}\cdot P^{DR}_{m,d,t,s}\right) + [1-u_{m,t,s}]\cdot c^{LR}_t \sum_{l\in L_m} P_{m,l,t}\right\} + \\ M\cdot\sum_{s\in S} p_s \sum_{l\in L}(1-v_{l,t,s})\cdot\alpha_l P_{l,t} \end{cases}$$

Cost of purchasing reserves

Cost of power from resources

Load shed penalty

- **Subject to:**

$$\forall s,\forall t: P^{sub}_{s,t} + \sum_{m\in M}\left(\sum_{g\in G_m} P^{gen}_{m,g,t,s} + \sum_{d\in D_m} P^{DR}_{m,d,t,s}\right) = \sum_{l\in L} v_{l,t,s}\cdot P_{l,t}$$

$$\forall s,\forall m,\forall t: (1-u_{m,t,s})\cdot\left(\sum_{g\in G_m} P^{gen}_{m,g,t,s} + \sum_{d\in D_m} P^{DR}_{m,d,t,s}\right) \geq (1-u_{m,t,s})\cdot\sum_{l\in L_m} P_{m,l,t}$$

$$\forall s,\forall m,\forall g,\forall t: 0 \leq P^{gen}_{m,g,t,s} \leq P^{res}_{m,g,t} \leq P^{max}_{m,g} \qquad \forall s,\forall t: 0 \leq P^{sub}_{t,s} \leq P^{sub,max}$$

$$\forall s,\forall m,\forall d,\forall t: 0 \leq P^{DR}_{m,d,t,s} \leq P^{res}_{m,d,t} \leq P^{max}_{m,d} \qquad \forall s,\forall l,\forall t: S^2_{l,t,s} = P^2_{l,t,s} + Q^2_{l,t,s} \leq (S^s_l)^2$$

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Power Grid and Natural Disasters

First Stage Variables				Recourse Variables	Scenarios											
					λ = 0.50			λ = 0.60			λ = 0.70			λ = 0.80		
				P_{sub}	11.691			13.738			14.941			15.975		
				Q_{sub}	4.708			5.343			5.528			6.005		
	a	b	c		a	b	c	a	b	c	a	b	c	a	b	c
$P_{r,2,1}$				$P_{g,2,1}$												
$P_{r,2,2}$	0.300	0.400	0.400	$P_{g,2,2}$	0.300	0.400	0.400	0.284	0.400	0.400	0.245	0.400	0.356			0.019
$P_{r,4,1}$				$P_{g,4,1}$												
$P_{r,4,2}$		0.046		$P_{g,4,2}$		0.046			0.046			0.046			0.046	
$P_{r,4,3}$				$P_{g,4,3}$												
$P_{DRR,1,1}$				$P_{DR,1,1}$												
$P_{DRR,1,2}$				$P_{DR,1,2}$												
$P_{DRR,1,3}$				$P_{DR,1,3}$												
$P_{DRR,2,1}$		0.052	0.040	$P_{DR,2,1}$		0.052	0.040		0.052			0.052				
$P_{DRR,2,2}$		0.184		$P_{DR,2,2}$		0.184			0.184							
$P_{DRR,2,3}$				$P_{DR,2,3}$												
$P_{DRR,2,4}$			0.300	$P_{DR,2,4}$			0.300			0.194						
$P_{DRR,3,1}$	0.062			$P_{DR,3,1}$	0.062			0.062								
$P_{DRR,3,2}$	0.160			$P_{DR,3,2}$	0.160			0.160								
$P_{DRR,3,3}$	0.080			$P_{DR,3,3}$	0.080			0.040								
$P_{DRR,3,4}$	0.160			$P_{DR,3,4}$	0.160			0.160								
$P_{DRR,3,5}$	0.080			$P_{DR,3,5}$	0.080											
$P_{DRR,4,1}$				$P_{DR,4,1}$												
$P_{DRR,4,2}$				$P_{DR,4,2}$												
$P_{DRR,4,3}$		0.001		$P_{DR,4,3}$		0.001			0.001							
$P_{DRR,4,4}$				$P_{DR,4,4}$												
$P_{DRR,4,5}$				$P_{DR,4,5}$												
$P_{DRR,4,6}$				$P_{DR,4,6}$												
$P_{DRR,4,7}$				$P_{DR,4,7}$												
				u_1	1			1			1			1		
				u_2	0			1			1			1		
				u_3	1			1			1			1		
				u_4	1			1			1			1		
				Load Shed	71, 75, 86, 94, 95			71, 75, 86, 96			71			96		

Fire approaching line 53-54, which affects a large section of the network. λ represents the ratio of available line capacity to maximum capacity. For more information, see: B. Ansari and S. Mohagheghi, "Optimal Energy Dispatch of the Power Distribution Network during the Course of a Progressing Wildfire," *International Transactions on Electrical Energy Systems*, vol. 25, no. 12, pp. 3422–3438, December 2015

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Concluding Remarks

- Difficult problem to solve when time horizon extends beyond a day or two, or if there is a need for granular dispatch
- Exact problem is almost always nonlinear mixed-integer
- Incorporating reactive power into the formulations makes the problem quadratic and sometimes non-convex
- The problem is typically multi-objective with usually contradictory functions, and Pareto optimality need to be ensured
- Success depends on having "reasonable" uncertainties

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