Models for managing the impact of an influenza epidemic

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Motivation

- Mutations of influenza virus
  → fears of a pandemic
- Research:
  - Mortality and morbidity
    → public health interventions
  - Workforce shortfall
  - Congestion in hospitals and clinics

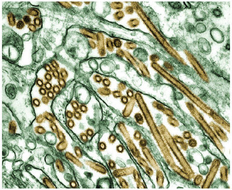

Figure: H5N1.

- Objective: Alleviate the impact of the epidemic on the operations continuity of critical infrastructure

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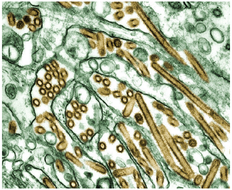

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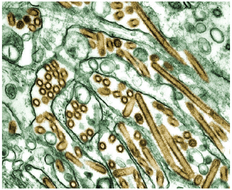

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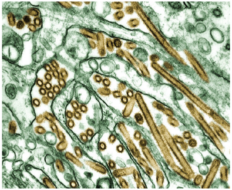

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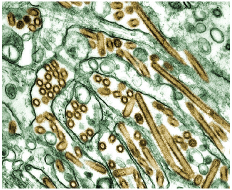

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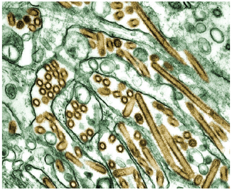

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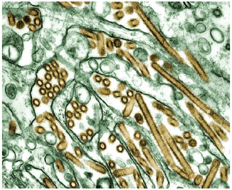

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Contingency planning

- Workers getting sick → bring in surge staff
- Restrictions:
  - Pool is finite
  - Available for a fixed period of time
  - Lag between request and availability
  - Exposed to epidemic too
- Planning horizon - Full preplanned strategy
- **When** and **how many** to bring in?

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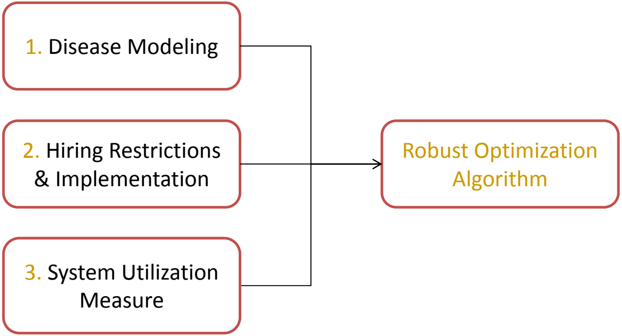
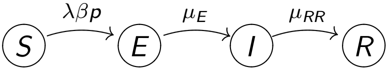
Building blocks

1. Disease Modeling
2. Hiring Restrictions & Implementation
3. System Utilization Measure

Building blocks



Disease Modeling



- S Susceptible
- E Exposed (Latent)
- I Infectious
- R Recovered

λ	contact rate;
β	$\mathbb{P}\{\text{meet I}\}$;
p	$\mathbb{P}\{\text{infection}\}$;
μ_E	incubation rate;
μ_{RR}	recovery rate.

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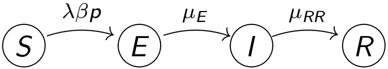

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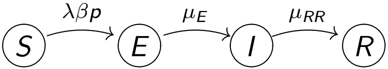

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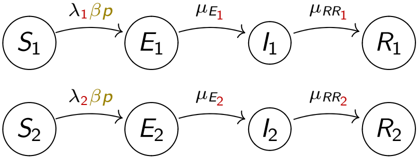
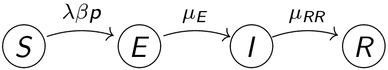
Account for workforce **separately**:



$\rightarrow$ General Population

$\rightarrow$ Workers

Disease Modeling



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Discrete Time Model: for subgroup j at time $t+1$:

$$
\begin{aligned}
S^j_{t+1} &= S^j_t e^{-\lambda_j * \beta_t * p} \\
E^j_{t+1} &= E^j_t e^{-\mu_{E_j}} + S^j_t (1 - e^{-\lambda_j * \beta_t * p}) \\
I^j_{t+1} &= I^j_t \; e^{-\mu_{RR_j}} + E^j_t (1 - e^{-\mu_{E_j}}) \\
R^j_{t+1} &= R^j_t + I^j_t (1 - e^{-\mu_{RR_j}}).
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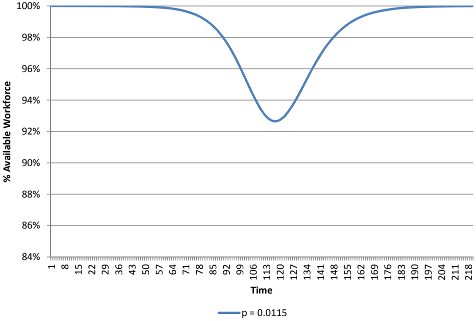
- $\lambda \beta p$ **?**
- Embed uncertainty on **p** (prob of contagion)

Hedge against uncertainty



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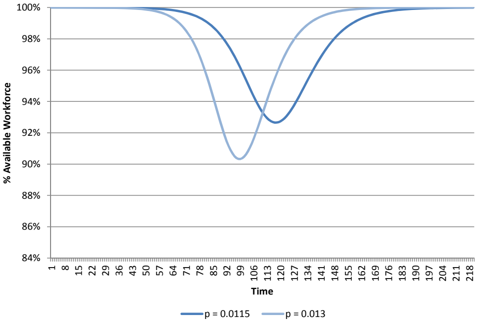

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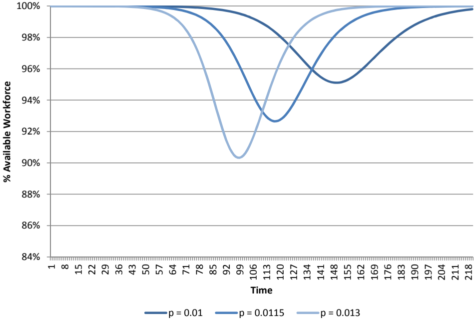

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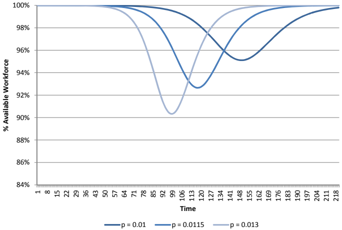

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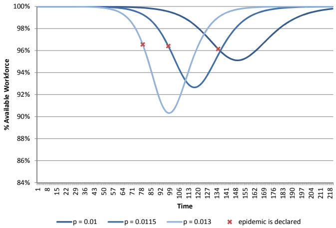

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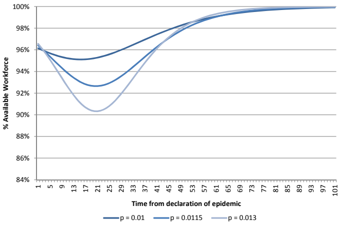

3. System Utilization Measures

Compute cost per day and add up. Consider 2 scenarios:

- Min WF level to operate,
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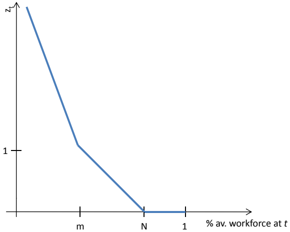

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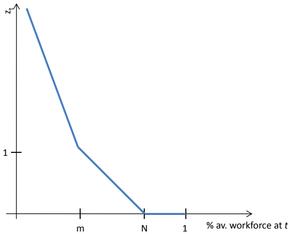

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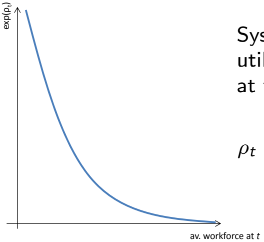
- Queue



System utilization at time t:

$$\rho_t = \frac{\lambda_t}{s_t * \mu}$$

$$\text{Cost} = \sum_t e^{K(\rho_t - \rho^*)^+} - 1$$

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$$V^* = \min_{h \in H} \max_{p \in P} V(h|p)$$

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- Generalized Benders' decomposition

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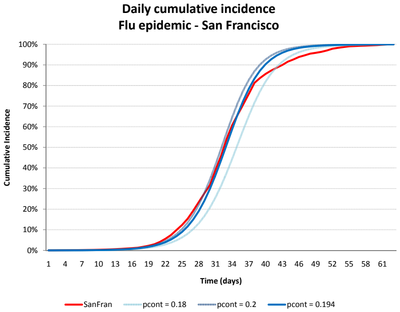

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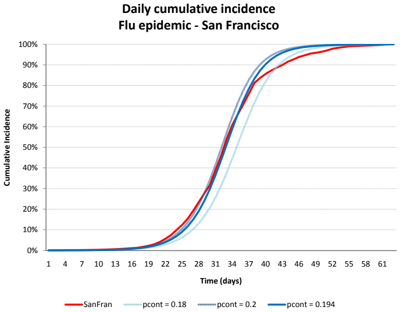


- $p \leftarrow (p_1, p_2, d)$

Example - Profile

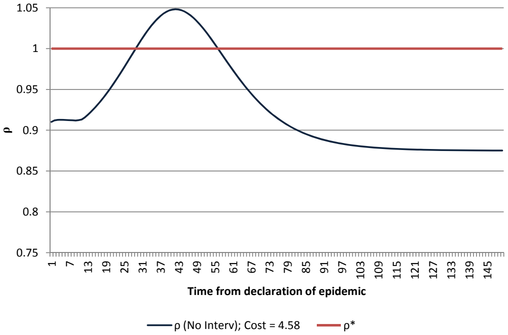
- **Demographics**

	General Population	High Risk Population
Size	900,000	20,000
Initial infected	5	0
Contact rates (per day)	30	35
Incubation rate (µE)	10/19	10/19
Removal rate (µR)	10/41	10/41
Survival prob (f)	1	1

- **Uncertainty Set**
  - $P = [0.01, 0.012] \times [0.0125, 0.0135]$
  - p can change on day $\{140, \ldots, 160\}$
- **Procurement Considerations**
  - Can bring up to 3,000 volunteers
  - Stay up to 1 week
- **Social Contact Model**
  - Nonhomogeneous-mixing
  - Damp contact rates by 30% when epidemic is declared
- **Queueing Cost**

Example - Scenario 1

Worst case: $(p_1, p_2, d) = (0.0109, 0.0135, 140)$ Cost: 4.58



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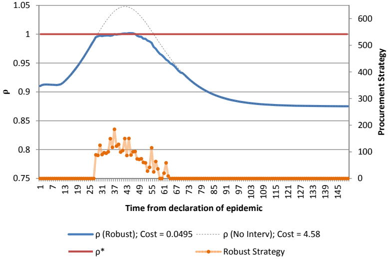

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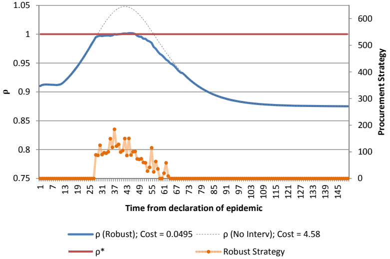
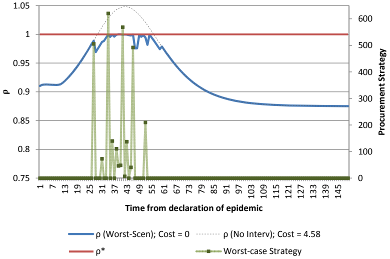


Naive worst-case

Cost: 0



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Given Robust strategy is implemented:

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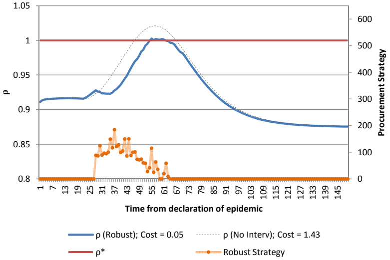

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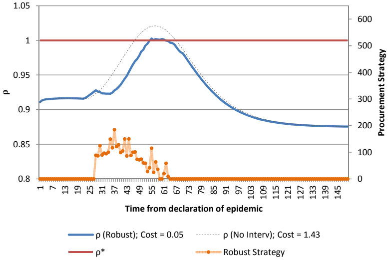
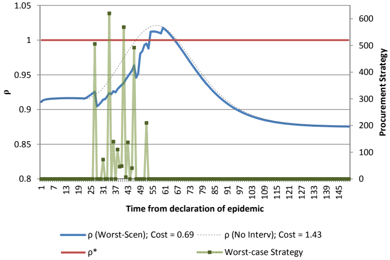


Naive worst-case

Cost: 0.69



Example - Comparing strategies

		No Intervention	Robust Strategy	Worst-Case Strategy
No intervention:	Cost	4.581	0.050	0.000
worst tuple	Maximum ρ	1.002	1.048	1.000
(0.01092, 0.0135, 140)	Critical days ($\rho > 1$)	28	8	0
Robust Strategy:	Cost	1.694	0.052	0.686
worst tuple	Maximum ρ	1.024	1.003	1.017
(0.01168, 0.0135, 140)	Critical days ($\rho > 1$)	21	7	12
Worst-case Strategy:	Cost	1.430	0.050	0.710
worst tuple	Maximum ρ	1.021	1.002	1.018
(0.01172, 0.0135, 140)	Critical days ($\rho > 1$)	20	8	13

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Takeaway: Planning against worst-case scenario may **not** be enough!

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- Focus on critical staff levels.
- SEIR model + adversarial models (contagion rate).
- Present efficient and accurate algorithms $\rightarrow$ procurement strategies which optimally hedge against uncertainty.
- Need to prepare for more than just the worst case scenario.

Thank you!

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