Network approaches to reducing infections in healthcare facilities
COVID-19 clusters

- 152 clusters worldwide (up to April 20, 2020):
  - 2/3 in closed settings
  - 7% involved >100 cases: hospitals, elderly care, religious gatherings, worker dormitories, ships

- 9,360 confirmed cases in Italy (April 7 - May 7, during lockdown):
  - ~60% in elderly care or similar
  - ~9% in hospitals
  - ~20% households

- 11 clusters and sporadic cases in Japan (up to Feb 28):
  - risk of transmission in closed settings ~20 times risk in open air settings

- Imported vs. local cases worldwide (up to Feb 27)
  - 80% secondary cases generated by ~10% infectious individuals

Leclerc et al 2020; Nishiura et al 2020; ISS; Endo et al. 2020
Superspreading events (SSE)

- SARS, MERS, Ebola
- explosive early growth, later sustained transmission
SSE drivers

- Host-specific
- Environmental
- Behavioral

- Co-location
- Closed setting
- Contacts

Lloyd-Smith et al 2005; Frieden et al 2020
proximity contacts

Polgreen et al. 2010
Isella et al. PLOS One 2011
Hornbeck et al. 2012
Vanhems et al. 2013
Lowery-North et al. 2013
Obadia et al. 2015
Hertzberg et al. 2017
Duval et al. 2019

Sociopatterns.org
short-stay geriatric unit

University Hospital, Lyon, France
75 individuals

Vanhems et al. PLOS One (2013)
contacts
contacts


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interventions

- Isolation
- Hand washing
- Nurse cohorting
- Contact removal

interventions

ISOLATION

HAND WASHING

NURSE COHORTING

CONTACT REMOVAL

healthcare workers

patients

temporal network epidemiology
from R to epidemic risk

from R to epidemic risk

from R to epidemic risk

from R to epidemic risk

Infection propagator approach

\[ P = \prod_{t=1}^{T} \left( 1 - \mu + \lambda A^{(T-t)} \right) \]

largest eigenvalue

\[ \rho \left( P(\lambda_c, \mu) \right) = 1 \]

Open code at: www.epicx-lab.com/tools.html

epidemic risk after intervention

risk increase  risk reduction

transmissibility

critical transmissibility $\lambda_c$

EXTINCTION  SPREAD

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epidemic risk after intervention

risk increase  risk reduction

critical transmissibility $\lambda_c$  transmissibility

EXTINCTION  SPREAD

ISOLATION  CONTACT  REMOVAL
“superspreaders”

HAI=healthcare-associated infection, e.g.:  
- methicillin-resistant Staphylococcus aureus (MRSA)  
- vancomycin-resistant Enterococci (VRE)
“superspreaders”

HAI=healthcare-associated infection, e.g.:
- methicillin-resistant Staphylococcus aureus (MRSA)
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reorganizing nurse shifts

EMPIRICAL

Nurse $i$

$\alpha_i(t) = 1$

$a_i(t+1) = 1$

Nurse $j$

$\alpha_j(t) = 1$

$a_j(t+1) = 0$

REORGANIZED

Nurse $i$

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Nurse $j$

$a_j(t) = 1$

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reorganizing nurse shifts

\[ V = -\frac{k}{2} \sum_i \sum_{t_1} \sum_{t_2} a_i(t_1)a_i(t_2)(t_1 - t_2)^2 \]

\[ k = -1 \quad \text{REGULAR SCHEDULE} \]

\[ k = 1 \quad \text{IRREGULAR SCHEDULE} \]
reorganizing nurse shifts

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$k = -1$

REGULAR SCHEDULE

$k = 1$

IRREGULAR SCHEDULE

it preserves:

- #/ type/duration of contacts
- quality of care

+ constraints:

- Shift duration ($S$)
- Workload ($W$)

Valdano et al medrxiv 19007724 (2019)
infection control

Constraints

HAI risk reduction (%)

equivalent % NN contact duration removed

Valdano et al medrxiv 19007724 (2019)
infection control

Constraints

HAI risk reduction (%)

variation #nurses per patient

Equivalent % NN contact duration removed

Valdano et al medrxiv 19007724 (2019)
infection control

Valdano et al medrxiv 19007724 (2019)
nurse scheduling + HAI control

potential $V$

+ hard constraints:
  - Shift duration ($S$)
  - Workload ($W$)
  - Hospital-specific
  - Ward-specific

+ soft constraints:
  - Days off
  - Part-time nursing personnel
  - Additional personnel (phys therapists, nutritionists,...)
  - … …
acknowledgments

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www.epicx-lab.com
[we're hiring]

Valdano et al. PRX (2015)
Valdano et al. PRL (2018)
Darbon et al. RSOS (2019)
Valdano et al. medrxiv 19007724 (2019)