An exposure-dependent transmission model for simulations of disease spread

Timo Smieszek, Natural & Social Science Interface, ETH Zurich

❶ Objective

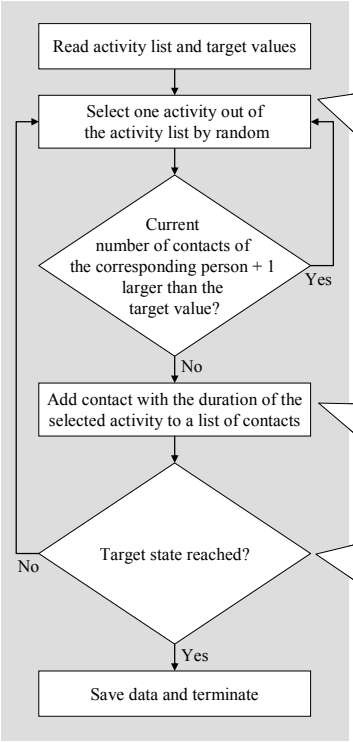
- Models of disease spread often assume constant per-contact transmission probabilities.
- Such an approach ignores that a short, random encounter might be less likely to transmit a disease than a long, intense contact.
- Infection probability is a function of the amount of infectious agents a person is exposed to [1, 2, 3].
- I use contact time as a proxy for the exposure to infectious material and test the effects of an exposure dependent transmission model on spread characteristics.

❷ Transmission model

$$P_{n,t_x} = 1 - \exp\left(-\Theta \sum_{m=1}^{I} q_{m,t_x} t_{nm,t_x} \right)$$

$P_{n,tx}$	Transmission probability for susceptible n at time t_x
Θ	Calibration parameter
$q_{m,tx}$	Shedding rate of infector m at time step t_x
$t_{nm,tx}$	Contact time of susceptible n and infector m at t_x
I	Total number of infectors

❸ Contact structure generation

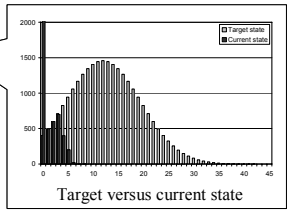


PersonID	ActivityNo	Duration
1	1	25 min
1	2	95 min
1	3	1320 min
2	4	1440 min
…	…	…
26104	101458	120 min
26105	101459	5 min
26105	101460	30 min
26105	101461	1405 min

Activity list

PersonID	Duration
…	…
1476	45 min
5678	15 min
487	1440 min
14325	120 min
1	***1320 min***

Contact list

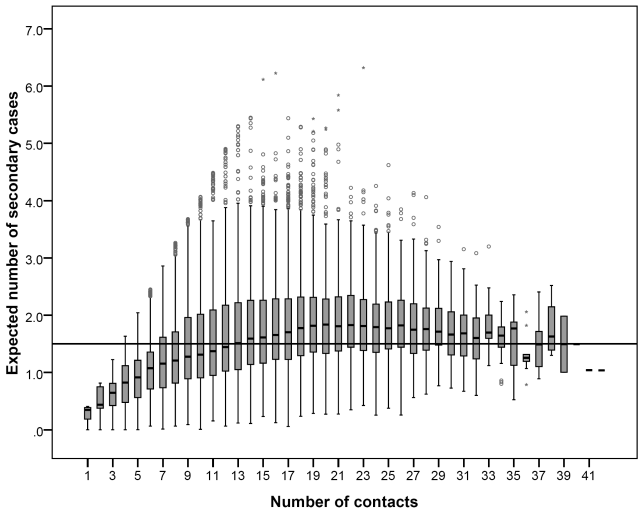


Target versus current state

Data sources [4, 5]

❹ Results

Expected number of secondary cases for a model adjusted to $R_0 = 1.5$ and based on a contact structure generated as described on the left (degree distribution $\mu = 13.0$; $\sigma = 7.5$):



- Models with constant per-contact transmission probability show a linear relation between the # of contacts and the expected # of secondary cases.
- The exposure-dependent approach results in a positive, but less than linear relation between these variables.
- In particular, a ~constant expected # of secondary cases seems to be reached for high # of contacts.

❺ Conclusions

- Simulating the effect of social distancing should not only focus on the number of contacts, but also on the contact duration.
- The importance of highly connected individuals (potential super-spreaders) might be overestimated in models with constant per-contact transmission probability.
- Further research on the impact of exposure-dependent transmission models on simulation outcomes is needed – in particular research using better data on the structure and duration of potentially contagious contacts.

References

[1] Haas CN, Rose JB, Gerba CP. Quantitative microbial risk assessment. New York: John Wiley & Sons, 1999: pp. 260–277.

[2] Wells WF. Airborne contagion and air hygiene. An ecological study of droplet infections. Cambridge (MA): Harvard University Press, 1955: pp. 123–151.

[3] Riley EC, Murphy G, Riley RL. Airborne spread of measles in a suburban elementary school. American Journal of Epidemiology 1978; 107: 421–432.

[4] Mossong J, et al. Social contacts and mixing patterns relevant to the spread of infectious diseases. PLOS Medicine 2008; 5: 381–391.

[5] Swiss Microcensus on Travel Behavior 2000, Swiss Federal Office for Statistics.