SIMULATION OF VIRAL INFECTION PROPAGATION THROUGH AIR TRAVEL

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There is direct evidence for the spread of common infectious diseases during commercial air travel, including influenza, SARS (Severe Acute Respiratory Syndrome), tuberculosis, and measles. This has motivated calls for restrictions on air travel, for example during the 2014 Ebola outbreak. However, such restrictions carry considerable economic and human costs. Ideally, decision-makers ought to take steps to mitigate the likelihood of an epidemic without imposing the above costs. Thus, science-based policy analysis can yield useful insight to decision-makers.

The effectiveness of a policy depends on the human response to it. Given inherent uncertainties in human behavior, we simulate a variety of scenarios and identify the vulnerability of policies under these potential scenarios. Supercomputing is used to deal with the large number of scenarios and the need for a short response time in cases of national emergencies. Our results identify new boarding procedures that can result in a substantial reduction in the risk of the spread of Ebola and SARS.

RESULTS & IMPACT
In our work, we used the above approach with Ebola. We studied the impact of different procedures for boarding, disembarkation, and seat assignment on infection spread. We showed that on a 182-passenger Boeing 767 airplane, random boarding can lead to substantial reduction in infection transmission compared with current zone-wise boarding. We have also obtained similar results showing the potential for changes in in-plane movement, deplaning procedure, seating arrangement, and plane sizes in reducing the likelihood of infection transmission. The improvements obtained for individual flights by these policy changes can be of substantial benefit over the course of an epidemic. Based on the transportation data from 2013, if unrestricted air travel were to have occurred during the 2014 Ebola epidemic, then the probability of generating 20 infections per month from air travel could have been reduced from 67% to 40% using better pedestrian movement strategies. This could further be reduced to 13% by exclusively using smaller 50-seat airplanes.

We have extended our approach to other directly transmitted diseases including SARS and influenza. This requires changes in approach that include aerosol and fomite transmission mechanisms, while pedestrian movement accounts for proximity among infectious and susceptible individuals. We have successfully extended the application to other high-density areas such as airport security-check areas and a generic airport gate. We also found effective strategies to mitigate spread by using temporary walls for queue management instead of ropes.

We developed a low-discrepancy parameter sweep that reduces by one to three orders of magnitude the number of parameter combinations that ought to be tried over the conventional lattice-based sweep (Fig. 2). We used number-theoretic properties of a low-discrepancy sequence to balance the load on the Blue Waters machine [4].

WHY BLUE WATERS
In a new emergency, due to lack of data, one usually needs to model for a variety of scenarios. This leads to a large parameter space of uncertainties, which requires a large computational effort. In addition, the models typically need fine-tuning, which leads to an iterative process where the model is repeatedly tuned based on results from its previous validation step. Consequently, rapid turn-around time is critical, which requires massive parallelism. Such parallelism becomes even more crucial during the course of a decision meeting, where results are typically needed in a short time. Toward that end, we obtained support from the Blue Waters team to optimize parallel I/O in our code to reduce simulation time by a factor of two.

REFERENCES


Figure 1: Schematic of the SPED fine-scale model combining pedestrian movement and infection dynamics.