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SIMULATION OF VIRAL INFECTION PROPAGATION DURING AIR TRAVEL

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EXECUTIVE SUMMARY

There is direct evidence of the spread of infection during commercial air travel for common infectious diseases including influenza, Severe Acute Respiratory Syndrome (SARS), 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 restrictions. Toward that end, science-based policy analysis can yield useful insight to decision-makers.

The effectiveness of any policy depends on the human response to it. Given the inherent uncertainties in human behavior, the research team simulated a variety of scenarios and identified the vulnerability of policies under these potential scenarios. Supercomputing was used to deal with the large number of scenarios and the need for a short response time in case of national emergencies. The results identified new boarding procedures that, if implemented, can result in a substantial reduction in the risk of the spread of infectious diseases.

RESEARCH CHALLENGE

The researchers' goal is to develop models and a novel methodology that can provide insight to decision-makers on policies and procedures that will reduce the likelihood of infection spread during air travel. In addition, this research promises major advances in other disciplines such as pedestrian movement modeling, mathematics, epidemic modeling, computer science, and bioinformatics, with a consequent transformative effect on transportation infrastructure and management.

METHODS & CODES

The research team modeled pedestrians during air travel as particles using the force-field approach proposed by Helbing *et al*. [1]. Both pedestrian density and the speed of the immediate neighbor in a pedestrian line determine pedestrian speed and trajectory [2,3]. The team's modifications incorporated these aspects into the pedestrian movement model. The pedestrian trajectory information was then integrated with a discrete-time stochastic susceptible-infected model for infection transmission that accounts for demographic stochasticity and variations in susceptibility of the population. This approach provides insight into the consequences of policy choices that change passenger behavior at individual levels. The team input this information into a global phylogeography model to assess the impact of these policies at a global scale.

Inherent uncertainties in human behavior and insufficient data during the initial stages of an epidemic make accurate predictions difficult. The team parameterized the sources of uncertainty and evaluated vulnerability under different possible scenarios. The researchers used Blue Waters to deal with the computational load that arises from a large parameter space, as well as a low discrepancy parameter sweep to explore the space of uncertainties efficiently.

Phylogeography (the study of the historical processes that may be responsible for the contemporary geographic distributions of individuals) uses genetic mutation information and geographic locations of viruses to model the spread of epidemics across large geographic scales. The team used Blue Waters to analyze 264 full-genome Ebola sequences from Guinea, Liberia, Sierra Leone, Italy, the United Kingdom, and the United States. The research group also used the BEAST software installed on Blue Waters to implement the phylogeography model.

RESULTS & IMPACT

In prior work, the research team used the above approach with Ebola. They studied the impact of different procedures for boarding, disembarkation, and seat assignment on infection spread. That work showed that on a 182-passenger Boeing 757 airplane, random boarding can lead to a substantial reduction in infection transmission compared with the current zone-based boarding. The team also obtained similar results showing the potential for changes in in-plane movement, deplaning procedure, seating arrangement, and plane sizes to reduce the likelihood of infection transmission. The improvements obtained for individual flights by these policy changes can bring substantial benefits over the course of an epidemic. In fact, based on transportation data from 2013, if unrestricted air travel were to have occurred during the 2014 Ebola epidemic, then the probability of generating 20 infectives 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.

The researchers have extended their approach to other directly transmitted diseases including SARS and influenza. This required changes to include aerosol and fomite transmission mechanisms, while pedestrian movement accounts for the proximity between infectious and susceptible individuals. The team has successfully extended the application to other high-density areas such as airport security-check areas and a generic airport gate. The research group also found that different queueing strategies can generate a decrease in infection risk of up to an order of magnitude.

The team also developed a low discrepancy parameter sweep, which reduced the number of parameter combinations that ought to be tried by one to three orders of magnitude over the conventional lattice-based sweep. Using the number-theoretic properties of a low discrepancy sequence helped balance the load on the Blue Waters machine [4].

WHY BLUE WATERS

In an emergency, scientists usually need to model a variety of scenarios owing to a lack of data. 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 the previous validation step. Consequently, rapid turnaround 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 span. The Blue Waters support team helped optimize parallel I/O in the code to reduce simulation time by a factor of two.

PUBLICATIONS & DATA SETS

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S. Chunduri, M. Ghaffari, M. S. Lahijani, A. Srinivasan, and S. Namilae, "Parallel low discrepancy parameter sweep for public health policy," presented at the IEEE/ACM Int. Symp. Cluster, Cloud, Grid Comput., 2018.