Proceedings of the 2023 Winter Simulation Conference
C. G. Corlu, S. R. Hunter, H. Lam, B. S. Onggo, J. Shortle, and B. Biller, eds.

ASSESSING THE IMPACT OF SOCIAL NETWORK SETTINGS ON COVID-19 TRANSMISSION IN CRUISE SHIPS: AN AGENT-BASED MODELING APPROACH

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ABSTRACT

Cruise ship operations faced significant disruptions during the COVID-19 pandemic. Close quarters and dense populations of domestic and international travelers are an environment where viruses can spread easily. The cruise industry and public health partners continue to develop guidelines to control the spread of disease within these settings. In this study, we developed an agent-based model to simulate the spread of COVID-19 in cruise ship environments. The model considers various types of interactions, including passenger-passenger, passenger-crew, and crew-crew interactions within networks and the cruise ship population. We evaluated the impact of different social network settings, such as group travel sizes, intensity of interactions, and initial number of infection seeds on the spread of disease. The findings provide insights for public health decision-makers and the modeling framework can inform other modeling activities that rely on similar data streams.

1 INTRODUCTION

Cruise ship operations were heavily disrupted during the COVID-19 pandemic as many travelers from diverse populations congregated in close proximity for extended durations on ships. Multiple outbreaks on cruise ships were reported at the beginning of 2020 (Ito et al., 2020), promoting ongoing efforts from local and federal public health agencies to develop and implement guidelines to control the spread of disease and ensure the safety of the travelers and crew members (Centers for Disease Control and Prevention, 2022).

While public health responses have focused on the evaluation of interventions for reducing disease transmission within larger communities, there has been limited research dedicated to measures specifically tailored to the unique environment of cruise ships. It is important to investigate how passenger and crew networks affect the spread of disease given that cruise ship settings can vary in capacity, target demographic (e.g., families, young adults, retirees, etc.), physical space, and onboard activities that promote interactions between passengers and crew members. In this study, we investigate the influence of social network settings within cruise ships on the transmission of COVID-19.

2 METHODOLOGY

We developed an agent-based model to simulate the spread of COVID-19. The model consists of two agent categories: passengers and crew members. Each passenger is assigned to a travel group, while crew members are assigned to cabin groups. Agents are assigned to age groups that represent the demographic composition observed on cruise ships. COVID-19 transmission dynamics are modeled using six health states: susceptible, exposed, infected asymptomatic, infected symptomatic, hospitalized, and recovered. At the start of the simulation, all agents are labeled as susceptible, except for those seeded as infectious pre-

travel. The durations spent in each health state and the transition probabilities between them follow the epidemiological parameters associated with the Omicron variant (Tanaka et al., 2022).

Every simulation day agents interact with all the other agents within their designated network (travel/cabin and activity-based networks.). Infections occur with a probability of contagion p when a susceptible agent and an infected agent interact. The probability of contagion p depends on the type of network the interaction occurs. The model parameters have been calibrated using outbreak data and literature (Jenness et al., 2021).

The primary outcome measure is the cumulative number of infections at the conclusion of the cruise ship voyage on day 10. Secondary outcomes include the direction of infection (i.e., who infected whom) and travel-related characteristics of the infected agents to better understand the impact of social networks on the spread of the disease within the cruise environment.

3 SIMULATION SCENARIOS

We evaluated a range of scenarios to address the following questions: (1) How does the size of travel groups influence the total number of infections?, (2) does varying the size of the travel group in which the initial infection is seeded significantly affect the number infections?, and (3) what is the impact of reducing/increasing the number of interactions on the total number of infections?

We conducted 1,000 replications per scenario and reported the average total number of infections with their corresponding 95% confidence intervals.

4 RESULTS AND DISCUSSION

The simulation shows that the network settings significantly affect the number of cumulative infections. The results provide insights into the varying outbreak risk profiles of cruises given their target demographic and the extent of community interactions facilitated by onboard activities. The simulation tracks the direction and type of infection which allows the identification of the drivers of infection to develop effective network modifications to reduce disease spread.

FUNDING

This research was supported in part by National Science Foundation (NSF) grant #2200269 and NSF grant #2246678. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the funders.

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