CIM-2021-U-030862-Final

SAFER-C™



Getting Back to Normal: Informing Renormalization of COVID-19 Risk-Minimized Activities for a 100-Bed Jail Housing Unit using SAFER-C™, an Agent-Based Model

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Abstract

During the coronavirus disease 2019 pandemic, US jails have faced challenges in providing safety, security, programming, and care while limiting virus transmission. Data-driven insights can help inform correctional leaders as they seek to transition to more normalized operations. We customized an agent-based model, Simulation Applications for Forecasting Effective Responses in Corrections (SAFER-C™), to simulate the operations, environment, and virus spread within a representative 100-bed housing unit, using de-identified data from District of Columbia Department of Corrections. Simulations indicated that most infections occur via staff-to-staff and inmate-to-inmate interactions, that benefits from higher facility vaccination rates are offset by the lower vaccination rates among intakes, and that resuming high-contact activities (e.g., basketball) may cause outbreaks. Simulation results aligned closely with practitioner experience. The detailed insights gained from this analysis suggest that SAFER-C™ is a valuable tool for correctional decision-makers.

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Acknowledgements

The authors wish to thank several individuals who provided insights and review of the SAFER-C™ model, and this final report. Specifically, the following reviewed results of Phase I and Phase II:

- **Dr. Beth Jordan**, MD Medical Director, DC Department of Corrections
- **Dr. Eleni O'Donovan**, MD Medical Director, Unity Health Care Inc., at DC Department of Corrections
- **Dr. Preetha Iyengar**, MD Supervisory Medical Officer, Chief, Outbreak Investigation Unit, COVID-19 Response, Center for Policy, Planning and Evaluation, DC Health
- **Dr. Anil Menon**, MD Acting Supervisory Medical Officer, Chief, Outbreak Investigation Unit, COVID-19 Response, Center for Policy, Planning and Evaluation, DC Health
- **Shreya Khuntia**, MBBS, MPH, Infectious Disease Epidemiologist, Epidemiology Investigation Team (Outbreak Investigation Branch), COVID-19 Emergency Response

We also extend our appreciation to **Bahram Yousefi**, PhD – who generated the stratified deidentified samples of resident and staff records used to generate the simulations.

Finally, the authors would like to acknowledge **Tammy Felix** for her leadership and project management in this work, **Tim Beres** and **James "Chip" Coldren**, PhD, for their guidance and vision in applying SAFER-C™, **Jessica Dockstader** for her assistance in project planning and subject matter expert interviews, **Yee San Su**, PhD, for developing the first prototype of the SAFER-C™ model, **Bradley Dickey**, PhD, for creating the base model upon which SAFER-C™ was derived, and **CNA leadership** for their funding and support of this work.

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Cover Image Credit: DC DOC

Graphic Designer: Kimberly Dillon

Approved by: September 2021

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EXECUTIVE SUMMARY

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has severely disrupted every facet of American life, including the correctional system. Nationwide, prisons and jails continue to face challenges in providing safety, security, programming, activities, and care while limiting coronavirus transmission, and correctional leaders and administrators continue to look for operational solutions that promote both safety and rehabilitation under difficult circumstances. The District of Columbia Department of Corrections (DC DOC) is no exception. In this paper, we discuss the DC DOC experience with COVID-19 and a new simulation planning tool developed specifically to help corrections officials manage under pandemic conditions.

Confronted by facility designs such as dormitory housing or large housing units in aging linear facilities, limited access to testing, rapidly evolving knowledge about COVID-19 transmission, mutating strains of virus with increased transmissibility and resistance to vaccines, and incarcerated individuals who decline vaccinations when offered, leadership necessarily responded by implementing medical stay-in-place operations. Such operations severely limited group sizes and out-of-cell activities. Contact with persons who might have had significant community exposure was limited to essential personnel—staff and essential service contractors (food service, health service, etc.)—required to sustain daily operations. Programs and visits became virtual, often via tablets, offering emails, texts, and virtual visiting applications. In-person visits, religious services, education, work programs, and high-contact activities such as basketball were halted or severely modified to protect the health and safety of residents, staff, and providers.

Correctional leaders at DC DOC sought to transition to normalized operations with optimal health protection. Science-based effective normalization strategies require insight into COVID-19 transmission risks associated with various types of human interactions and activities. For jails, where significant throughputs continue, data-informed insight into the impact of vaccination efforts on normalization of activities is essential for continued protection of health. In this paper, we demonstrate how innovative, data-driven models combined with analysis of role-based interactions and an understand of jail operations can be used to generate this insight..

MOTIVATION

This work used an agent-based model (ABM) to simulate the individual interactions of staff and residents in a jail facility and the resulting virus spread among these populations. We modeled several scenarios for a jail facility in order to evaluate the risks of resuming various activities and programs during the COVID-19 pandemic. We formulated and executed realistic simulations to quantify the potential virus spread resulting from common reopening decisions faced by jails nationwide. These simulation results provide insight to support jail leadership's decisions as they transition to higher activity levels and resume out-of-cell activities while mitigating and managing COVID-19 transmission risks.

SAFER-C™ MODEL

CNA developed the Simulation Applications for Forecasting Effective Responses in Corrections (SAFER-C™) disease spread model, based on a model CNA developed for Navy vessels, in 2020 in response to the COVID-19 pandemic. Following a successful pilot of the SAFER-C™ model in the Minnesota Department of Corrections prison facilities, CNA collaborated with DC DOC to adapt this model for jail facilities.

SAFER-C™ is unique in that it uses an agent-based approach to study virus transmission at the individual level in a correctional facility, as opposed to the aggregate population level. The model simulates one-to-one interactions between residents, staff, and external persons in a jail facility or housing unit over a set time period. Based on the frequency and intensity of these interactions, the demographics of the individuals in close contact, and public health disease parameters, the model uses a stochastic approach to evaluate how a virus may spread from individual to individual throughout the facility. SAFER-C™ can be customized to the needs of a specific facility and can be used to assess "what-if?" scenarios.

METHODOLOGY

This work proceeded in two phases. In the first phase, we formulated an initial model based on information about facility operations and policies, and de-identified resident and staff data, provided by DC DOC. We modeled a 100-bed housing unit in a jail facility with a random daily throughput of five to 25 residents over a 25-day period. The housing unit population was maintained at 100 throughout the simulation. We designed the model inputs to reflect medical stay-in-place conditions. All non-essential programs, classroom education, visits, religious services, and high-contact recreational activities were halted, while 20 essential activities (e.g., recreation, tablet-based education and programs, commissary, mail, laundry, meeting with case management) continued with precautions. Intakes[1] were assumed to be quarantined, and symptomatic cases were assumed to be isolated for 14 days. There were two entry points for the virus: from staff contact with the external community and from a randomly seeded resident. The model results include both symptomatic and asymptomatic infections; thus, model estimates likely exceed the number of infections observed in practice[2]. We assumed that infections would spread unabated for the 25-day simulation period[3]. The results of 10,000 iterations of the model were presented to DC DOC subject matter experts and practitioners in Health Services Administration and Infectious Disease Control intimately familiar with on-the-ground COVID-transmission experiences. They corroborated the results.

In the second phase, we developed a Baseline case and eight scenarios. We focused on three major questions:

- What is the effect of increasing the number of residents interacting together during out-of-cell time (assuming no social distancing)?

1 The term intakes also includes any resident with substantial community contact, e.g., from a court appearance.

2 In practice, interventions (contact tracing, mass testing, cell restrictions/quarantine pending test results, enhanced symptom monitoring) are implemented immediately upon detection of the first case in order to detect and dampen infection spread.

3 This was akin to experiences in the facility during the early days of COVID before mass testing was facilitated by the availability of an Abbot testing machine and reagents on-site.

- What is the effect of different vaccination rates among the resident population?
- What is the impact of reintroducing high-contact activities (e.g., basketball)?

MAJOR FINDINGS

Our major findings were as follows:

- Infections were more commonly transmitted from staff to staff and from resident to resident than through any other pathways (e.g., staff to resident, or resident to staff).
- The highest risk activities involved community-to-staff interactions, daily staff-to-staff interactions, resident out-of-cell time, pat-downs and searches, and movement of residents outside the housing unit.
- The average risk of infections was observed to vary only slightly with the number of residents (i.e., 10 to 20 to 40) allowed out-of-cell simultaneously, but the risk of a severe outbreak was observed to increase with larger group sizes.
- Infections can be higher in groups of vaccinated and unvaccinated persons engaging in activities together without social distancing (e.g., using phone banks). Vaccinated individuals who are infected are often asymptomatic, thus behaving like additional seeds, and may continue to transmit infection undetected until the first symptomatic case is observed which then triggers quarantine and unit-wide testing protocols.
- The Baseline case resulted in an average of 3.6 resident cases (maximum 29) and an average of 16.3 staff cases (maximum 37) over 25 days. An average of 12.8 staff cases, more than 80%, were from community spread. In addition, 98% of all iterations reported no resident fatalities while 79% reported no staff fatalities.
- The variation in the average number of resident infections (2.4-23.9) was greater than that for staff infections (16.3-17.8) in the eight scenarios.
- Increased initial vaccination rates (i.e., from 33% to 50% to 70%) did not result in differences in average overall infection rates. Due to high turnover rates in the housing unit, the observed average vaccination rate equilibrated to a value of approximately 36% during the simulation period.
- Resumption of high-contact activities (e.g., basketball) resulted in the highest average number of infections among the scenarios, especially when multiple infectious resident seeds were introduced. High vaccination rates were shown to lower the number of infections slightly.
- If intakes were not quarantined, the average number of resident cases increased to 31.0 over the 25-day period.

CONCLUSIONS

The findings from this work aligned well with practitioner observations at DC DOC. DC DOC used the insights mentioned above to inform its reopening protocols and responses to emerging concerns with infections from new strains. For example, the predominance of staff-to-staff and resident-to-resident transmission pathways resulted in reinforced messaging regarding social distancing cautions when interacting with peers. SAFER-C™ results also informed reopening decisions regarding group sizes and delay of resumption of high-contact basketball, especially in mixed groups or among unvaccinated residents. Simulations also helped explain a plateau in observed overall effective resident vaccination rates despite increased resident participation in vaccination efforts. Based on the insights gained and documented in this paper, we believe SAFER-C™ is a valuable tool for correctional environments that can help advance the use of data-driven insights by correctional leaders.

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JAIL RESPONSES TO THE COVID-19 PANDEMIC

Since March 2020, much has been learned about the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus that causes coronavirus disease 2019 (COVID-19) and its impact on populations, including jail populations. Jails are locally funded and operated justice system detention facilities, which function like cities within cities (or villages within villages). They hold predominantly individuals with yet-to-be adjudicated charges, and have significant rates of intakes from and releases to the community. During normal operations, jails provide individuals with the maximum amount of out-of-cell time that is safely permissible within the constraints of facility construction, staffing complements, and custodial risk levels of residents. This is because residents are acknowledged as legally innocent until adjudication indicates otherwise. It also provides everyone in custody, regardless of legal status, an opportunity to engage in activities that may help them leave better than they were when they entered.

Infection control and management of COVID-19 posed significant challenges in many jails. These persisted despite decarceration efforts; practicing social distancing; donning masks and other personal protective equipment (PPE) as indicated; limiting access to high-touch surfaces; using enhanced cleaning protocols; facilitating out-of-cell time in small cohort groups limited in size according to facility layout; regulating housing unit population levels; local health authority guidance; and even court orders. Individually and cumulatively, the intent has been to limit the possibility of infection spread and preserve the health of all within the jail's walls.

Early experiences led to strategies to conserve scarce testing capacity. Within jails, as well as the broader community, this included ruling out other potential causes such as flu, monitoring for symptoms as they presented, contact tracing, and testing only the symptomatic. Staff and contractors were subject to daily screening, temperature monitoring, being quarantined in the event of known exposure, engaging in limited community movements and social contacts, and being instructed to stay home if experiencing any symptoms of illness. Staff were (and continue to be) doubly concerned. Concerns include contracting infection from within facilities and infecting family or loved ones as well as contracting it from interactions in the community and transmitting to coworkers or facility residents. Later, as testing capacity improved and asymptomatic spread was recognized as important, jails implemented mass testing in housing units with recent outbreaks, and serial testing for residents entering the facility from the community or after exposure to the community, to limit transmission.

As the pandemic has continued, guidelines and recommendations for how correctional systems can manage COVID-19 risks have been developed by the Centers for Disease Control and Prevention (CDC, 2020a), American Correctional Association (ACA), National Sheriff's Association, and other countries, such as Canada (Ricciardelli, 2021). Challenges unique to jails were recognized and interventions were proposed (Williams, et al., 2020) (Wurcel, et al., 2020). A survey of lessons from past pandemics in correctional facilities suggested principles to guide policy and practice during the emerging pandemic (Beaudry, et al., 2020).

ANALYSIS OF VIRUS SPREAD IN JAILS

Over the last year, researchers have endeavored to better understand and document transmission and mitigation of COVID-19 in jails. Cook County, Illinois, a mega-jail system with over 10 facilities of various age and physical layout, documented the earliest detailed accounts of transmission (Lofgren, et al., 2020). Since then, various studies have contributed insights to virus spread and the effectiveness of testing strategies and mitigations in jails. Studies have also turned to mathematical modeling to simulate human and virus behaviors in jails.

Severely limited testing capacity in the early days of the pandemic spurred the emergence of two effective testing strategies for jails. Mass testing was offered in 14 prisons and two jails, one in California and one in Texas, where it was offered to 31.6% and 13.7% of those housed (approximately 1000 persons in each case) and shown to be effective respectively identifying 37.3% and 48.5% of those tested as positive (Hagan, et al., 2020). Both jails had cell-based as well as dormitory housing. Serial testing of 98 persons housed in five quarantined dormitories at a Louisiana jail with tests on days 1,4, and 14 after initiating the serial testing protocols (Njuguna, et al., 2020) offered an effective strategy to conserve testing resources when these were severely constrained. Researchers observed that 71 positives were identified through the mass testing, 54% on the test administered on day 1, 36% on the day-4 test, and the remaining 10% (2 persons) on the day-14 test. This study also indicated that pre-symptomatic (4%) and asymptomatic (41%) cases were of significant concern.

An assessment of a community originated infection transmission at a Utah correctional facility (Lewis, et al., 2021) that spread to two buildings and lasted several months clearly underscored the importance of PPE use, hand hygiene, limiting access to communal high-touch areas, social distancing, and limiting out-of-cell time to small cohort groups. It also emphasized the effectiveness of rapidly quarantining and conducting enhanced medical monitoring on housing units where infection has been detected. Whole genome sequencing of viral samples associated with an outbreak in a Wisconsin state prison between August 14 and October 22, 2020 (Hershow, et al., 2021) showed that the virus introduced by six infected new intakes in early August propagated and continued to infect 79% of prisoners and 26% of staff members during this period. The paper highlighted the importance of implementing a sufficiently long initial quarantine period after intake and the danger of inadequate initial quarantine periods.

Mathematical modeling was used to simulate the effect of ventilation, high-efficiency particulate air (HEPA) filter use, and mask use on the impact of SARS-CoV-2 virus transmission via aerosols in a multiroom facility over the course of two eight-hour shifts after exposure to an infected person (Kennedy, Lee, & Epstein, 2020). This work showed that colleagues sharing the same space with the infected person in poorly ventilated spaces with no masks and no HEPA filters were at the highest risk of infection. With improved ventilation, use of HEPA filters, and mask use, risk of infection was reduced by nearly 87 percent for co-workers sharing the same space during an eight-hour shift, and was reduced to negligible levels for those sharing the space in a following shift or those in spaces sharing the same ventilation system during the same shift.

Kırbıyık, et al. conducted a network analysis of interactions among staff members and residents of Cook County, Illinois, detention facilities over a two-month period, from March 1 through April 30, 2020 (2020). They calculated the number of connections between persons and divisions based on a value of one for each new resident/bed assignment, and each shift for staff members. Authors observed that connections between infected staff members occurred significantly more often than what would be expected from simply random encounters. They also observed that there were significantly fewer connections between residents—a result of restricted movements in-facility and within housing units, implemented to reduce the transmission of the SARS-CoV-2 virus. Person-to-person networks of people occupying the same housing units at the same time were mapped. The researchers observed that a joint network of residents and staff did not clearly indicate patterns of clustering or spread. Beyond the expected clustering of resident cases in the Residential Treatment Unit Division and Medical Isolation units, there were no clear patterns of clustering of infections noted at the division level. Residents who were infected had contact more often than what would be expected from merely random interactions. During the period when infections were increasing throughout facilities, the mean number of interactions between infected staff members was significantly higher than what would be expected from merely random interactions. The results indicated the importance of cohorting, maintaining consistent shift assignments, and using masks to control the spread of infections. The authors did not have the necessary data to analyze risk of infection by post type or staff role.

A stochastic dynamic transmission model describing the spread of COVID-19 in a large urban US jail was calibrated to a moving average of the daily reported cases. The reduction in transmission rate as a result of three major interventions—depopulation, single celling, and testing of asymptomatic persons—was quantified using the model (Malloy et al., 2021). The model indicated that these interventions likely prevented approximately 83% of projected cases over a period of 83 days.

AGENT-BASED MODELS (ABMS)

A particular type of modeling that has gained increasing popularity is the use of agent-based models (ABMs). ABMs employ a computational modeling approach that uses a "bottom-up" perspective to simulate the individual actions of autonomous agents to understand the behavior of a complex system. Agents are defined with specific properties and are simulated to interact with each other and with their environments using pre-defined rules. ABMs can represent heterogeneous populations where the behavior of each individual contributes to the overall outcome rather than assuming an aggregated population response.

ABMs have been applied to various public health challenges, including the spread of infectious diseases (Tracy, Cerdá, and Keyes, 2018). For example, Perez and Dragicevic (2009) developed a geographic information systems (GIS)-based ABM to simulate the spread of a contagious virus in the urban region of Vancouver, Canada. The authors considered the spatial movement and interactions of agents (i.e., workers and students) based on their mode of transportation and activities, and found higher instances of virus transmission occurring in participants of stationary activities (e.g., school and shopping) after commuting. More recently, ABMs have also been applied to the spread of SARS-CoV-2. Hoertel et al. (2020) developed a stochastic ABM to evaluate the effect of non-pharmaceutical interventions (NPIs) in France once lockdown regulations are lifted. The authors used past studies or assumptions to define the ABM parameters and found that NPIs coupled with shielding most vulnerable populations may help lower the number of new infections and severe illnesses. Hunter and Kelleher (2021) adapted an existing ABM for measles to the spread of SARS-CoV-2 in Ireland. The authors used known commuting and community patterns to validate the model and then to evaluate the effect of mitigation efforts such as vaccines and school closures in one rural Irish county. The study emphasized the importance of adjusting and tailoring model parameters.

In our white paper, we add to the body of knowledge related to control of infection transmission, specifically within jail settings, as it pertains to considerations for facilitating normalization of activities. Our paper is based on insights derived from simulations of an ABM developed by CNA using data provided by the District of Columbia Department of Corrections (DC DOC). This is particularly relevant as communities reopen and jails contemplate how to safely transition to normalized operations.

THE SAFER-C™ MODEL

BACKGROUND

The Simulation Applications for Forecasting Effective Responses in Corrections, or SAFER-C™, disease spread model is software program developed by CNA in 2020 in response to the COVID-19 pandemic (CNA, 2020; Dickey et al., 2020). The model builds on work CNA has done for the US Navy to model virus spread among sailors on naval ships (Dickey & Lim, 2020). CNA's Institute for Public Research (IPR) adapted the naval model for application to correctional facilities in new software program. Designed to help correctional leaders forecast and manage their facilities while facing an existing or potential virus epidemic, the SAFER-C™ model is a practical and valuable planning tool for helping corrections administrators make critical decisions regarding mitigation efforts to prevent disease spread, while protecting both residents and staff.

While many models developed as a response to the COVID-19 pandemic tend to focus on estimating model parameters (e.g., transmission rate R0) or aggregate population metrics, the CNA models track virus spread on an individual basis using an ABM approach. This modeling approach allows detailed insights into population-level simulations. Although computationally demanding for very large populations, ABMs of disease spread are well suited for simulating transmission in facilities (e.g., ships and prisons), and ABMs have been successfully employed to address cases involving several thousand individuals.

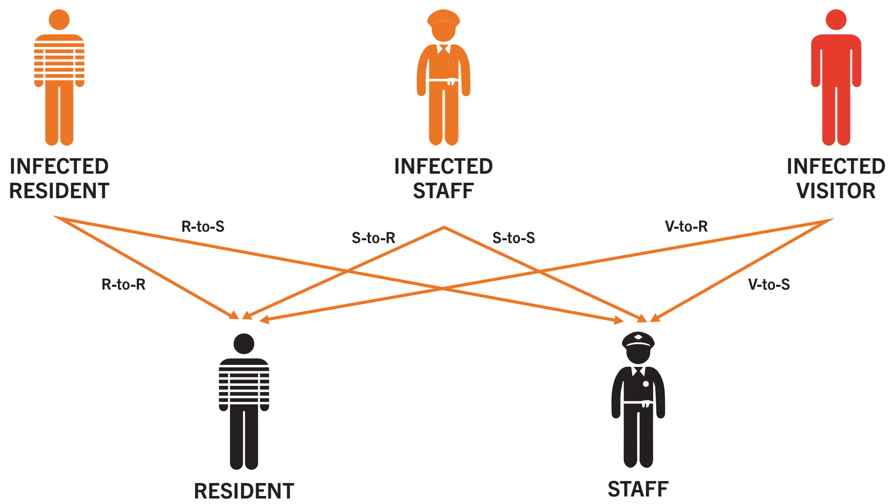
A key benefit of SAFER-C™ is that it enables decision-makers to compare options and answer a variety of "what-if?" questions about decisions pertaining to opening or closing certain programs or managing contacts within the facilities. By providing information about potential outcomes from these decisions (e.g., number infected and fatalities), the model can help correctional leaders identify lower risk strategies for restoring some prison activities.

HOW SAFER-C™ WORKS

SAFER-C™ is an ABM that tracks the daily interactions of residents and staff on an individual basis, using the groups that each infected individual belongs to as the likely conduits for spreading the virus. The model is unique in that it allows for acute customization that considers facility-specific operations and policies. It requires detailed input regarding the activities and attributes of each staff and resident, facility policies and operations, and estimated contacts between and among staff and residents. Each application of SAFER-C™ will require site-specific inputs to best represent the facility modeled. The specific inputs used for the analysis in this paper are described in detail in the Methodology section.

SAFER-C™ can consider a wide range of activities at a correctional facility in order to show the implications of virus spread from reopening, for example, work programs, education and treatment classes, religious programs, and visitations. The model considers the possibility of virus spread from close contacts between and among participating residents, corrections officers (COs), and other staff members or external individuals (e.g., volunteers). These transmission pathways are depicted in Figure 1. As an ABM, SAFER-C™ is able to model these activities in detail, specifying the frequency at which the activity occurs, the groups of individuals involved, the size of the groups, a probability distribution of the number of contacts between each group, and the likely degree of contact. Furthermore, SAFER-C™ can also model common mitigations that facilities may implement, including quarantine and isolation requirements, regular testing, contact testing, and vaccinations.

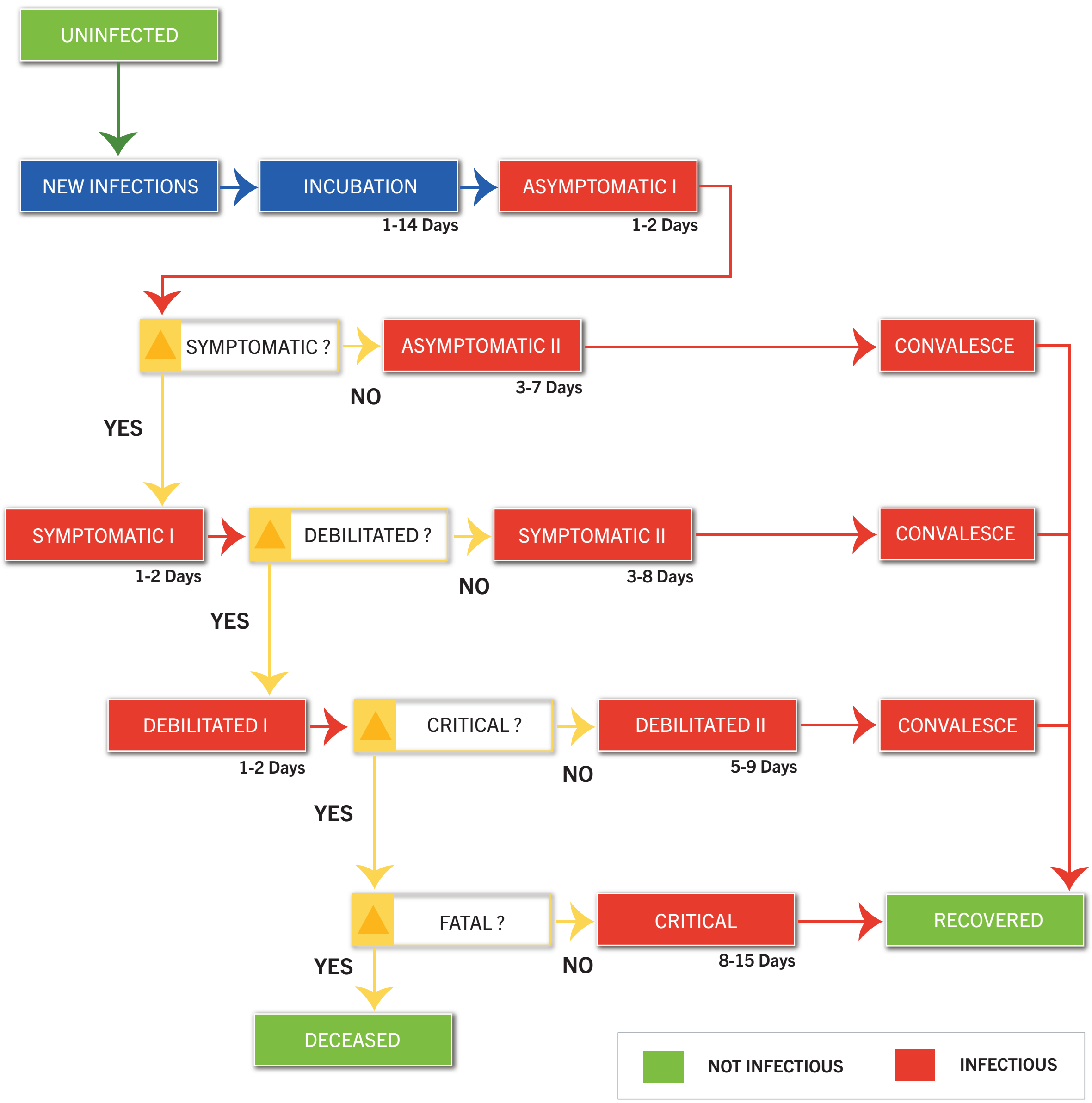
Figure 1. Types of virus transmission pathways considered in SAFER-C™



Source: CNA.

The epidemiological parameters found in SAFER-C™ are based on mathematical modeling guidance by the CDC (2020b). SAFER-C™ uses an infection progression pathway to simulate the stages of virus progression of each infected individual (Figure 2). The model tracks whether an infected individual will transmit the virus to another individual in close contact, how many days the virus will incubate in an infected individual, whether the individual will be symptomatic or asymptomatic, how long symptoms and infection will last, and whether the infection will progress to more critical stages.

Figure 2. SAFER-C™ virus progression pathway



Source: CNA.

The model is designed to account for uncertainty (e.g., in individual behavior) through random draws that simulate a variety of possible outcomes to determine the following:

- The estimated number of contacts with others that infected individuals have each day
- The specific individuals that come into contact with infected individuals
- The likelihood that virus transmission occurs
- The routes of disease progression that each infected individual follows (based on an individual's age)

As a probabilistic model, SAFER-C™ characterizes the range of possible outcomes of a defined simulation by running the daily activities of staff and residents thousands of times. The solution set thus provides decision-makers with insight into risk profiles for a particular scenario at the facility. As an ABM, SAFER-C™ also retains detailed information on groups of individuals and types of activities that generate higher rates of infection in the model iterations. These insights, identified through SAFER-C™ simulations, can substantively inform facility decisions.

PAST APPLICATIONS AND INSIGHTS

CNA first developed and piloted SAFER-C™ with the Minnesota Department of Corrections (MN DOC). The model was used to forecast disease transmission and progression over time in a secure MN DOC prison facility with over 500 staff and 1,500 residents. CNA analyzed several "what-if?" scenarios to provide insight into the risk involved in reopening various types of facility activities and programs at the prison. These included resuming work programs, volunteer programs, and structured visitation schedules. CNA then prepared a ranking of scenarios based on the likely number of infections that would result from resuming each of these activities individually. It was found that work programs would likely result in the greatest virus spread, followed by volunteer programs, and then visitations. CNA then performed a post-analysis of the sequence of events at a MN DOC facility that had experienced an outbreak. This second set of simulations pointed to the validity of the parameters used in the model by producing results within range of the actual events. These insights from SAFER-C™ were an important part of ensuring that MN DOC made informed decisions in deciding which activities to reopen at its facilities and when to do so (Dockstader et al., 2020).

METHODOLOGY

APPROACH

This paper describes a collaboration between CNA and the DC DOC to further adapt SAFER-C™ to jail facilities. We aimed to formulate and execute a series of SAFER-C™ scenarios to provide insight into pressing concerns for jail facilities nationwide regarding the resumption of activities and programs which were halted during the COVID-19 pandemic. This work reflects a typical 100-bed jail facility, or a 100-bed housing unit in a larger facility. Scenarios were developed based on subject matter expertise and data from DC DOC.

While DC DOC is a large jail with an average daily population of over 1500 residents, the simulation was conducted based on a hypothetical 100-bed unit. Housing units operate in a fairly self-contained manner—especially during COVID-19—except for the significant movement of persons in and out of the units on a daily basis because of constant intake and release movements. Most US jails are small to medium-sized jails that house about 100 or fewer persons. We believed that by simulating a 100-bed unit, and allowing it to receive fresh intake from the community with intake quarantine happening on the unit itself, we could better reproduce conditions in many facilities while still deriving sufficient insight to apply to DC DOC facilities. At DC DOC, as in jails with multiple housing units, intake quarantine usually occurs on a designated housing unit and residents enter other housing units only after they have been determined to be free of infection. Even so, it may be possible for a resident to contract the virus while being transferred from a different housing unit within the facility, after a medical or legal appointment in the community, or through other contacts with persons infected through community exposure who are pre-symptomatic or asymptomatic (not known to be infected at the time of contact). This corresponds to the source for the undetected seed for our simulations.

We used a two-phased approach. In the first phase, we collected a detailed stratified sample of resident and staff information and applied an understanding of jail operations to estimate reasonable parameters for the model for each type of interaction and each type of activity. The results of the initial analysis were then shared with colleagues from DC Health, including a national expert on infection spread in correctional facilities, as well as the Inmate Health Services medical staff from DC DOC and Unity Health Care (DC DOC's contractual inmate health services provider). These colleagues corroborated the results of the initial simulations from SAFER-C™ conducted with the intent of describing infection transmission within a housing unit of DC DOC facilities. This allowed the analysis to progress to the second phase, in which the same parameters were used to explore previously unencountered scenarios which were of interest in deciding how to reintroduce activities (and which ones to reintroduce) within DC DOC facilities without taking on excessive risk of transmitting COVID-19.

At the time of the analysis, COVID-19 vaccinations were being made available to correctional facilities and the general public, prompting correctional leaders to seek guidance on how to ensure the safe reopening of their facilities. Thus, in the second phase of the analysis, we aimed to generate SAFER-C™ scenarios that would help provide insights into the following questions for jail facilities:

- A common infection control practice for jail facilities is to significantly limit the number of persons simultaneously out of cell e.g., for recreation. While this practice significantly reduces infection transmission risk, it also severely limits the amount of out-of-cell/socialization time for each group. Whereas 40 people could receive four hours of recreation time, groups of 20 might only be able to receive two hours of recreation time. Maintaining social distancing and supervising proper mask use becomes increasingly difficult as group sizes increase. The question for jail leadership is how to improve socialization opportunities for residents while managing virus transmission risks. So we asked, what is the effect of group size on infection risk and severity (assuming no social distancing)?

- As COVID-19 vaccines are becoming widely available for correctional facilities, partially vaccinated staff and resident populations may allow facility activities to resume with lower risks. What is the effect of vaccination rate variation on infection risk and severity among the resident population?

- High-contact activities such as basketball and board games were halted in jail facilities during lockdown, but as well-liked resident activities, facility leaders are interested in understanding the risks associated with resuming such activities. What is the effect of reintroducing high-contact activities on infection risk and severity?

ASSUMPTIONS

We attempted to model in detail the activities and operations of a representative housing unit based on DC DOC data. We made the following major assumptions to account for uncertainties and limitations in the data and model parameters.

- We assumed a representative housing unit in a jail facility for all scenarios. While facilities may have multiple housing units, often with different resident demographics and programs, we modeled a single housing unit occupied with 100 beds, for simplification.

- We assumed the duration of simulation to be 25 days, based on the observed median length of stay of a resident at the housing unit. In addition, 25 days is beyond the maximum assumed length of virus incubation (14 days) in an individual; thus, the simulation allows the effects of transmission propagation to be seen. A simulation longer than 25 days might not be realistic, because additional mitigating policies (e.g., medical stay in place) would be implemented within that time period if an outbreak were to occur. In fact, the current practice is to quarantine housing units and medically monitor for three to five days, followed by mass testing, if a resident should test positive. This is done to limit the spread of infections. Bearing this in mind, the results of the simulations presented here should be considered worst-case scenarios of what could potentially occur if infections were to spread without any interventions. The results also inform us of relative "worst-case infection" risks of various activities.

- We assumed that intakes were quarantined before entering the general population. As facilities begin to normalize, such quarantine may also need to apply to those going to and from court appearances and medical clinic visits as well. Even though they are not new intakes, they may have been significantly exposed to external environments that would allow for community spread. The model would treat these individuals the same as new intakes.

- We seeded each iteration with a randomly infected resident to simulate an existing infection in the housing unit. To evaluate this assumption, we ran limited scenarios to see the effect of not quarantining intakes and of seeding with five infected residents. An alternate way of thinking about this assumption is to consider that intakes are insufficiently quarantined and that the community infection rate is such that every 25 days an undetected infected resident can enter the housing unit (or 100-bed facility); in the worst case, we modeled five undetected infected residents simultaneously entering the housing unit (or 100-bed facility).

- We assumed that all residents were housed in single cells. Thus, individuals could be restricted to their own cells without affecting housing capacity.

- We assumed that each staff member would come into close contact with two individuals in the community each day. These external contacts represented the effect of community spread and the possibility of outside infection entering the housing unit.

- We only considered staff that typically came into contact with residents and assumed that the staff served all housing units at the facility. Thus, a large staff pool of 892 was considered, with daily assignments randomly drawn[1].

- We selected parameters to model close contact between participating individuals in each activity based on the observations of one of the co-authors (a practitioner). Thus, expert judgment was used to establish these parameters. Based on DC DOC's actual experience during the pandemic, we arrived at two types of staff-to-resident interactions to model. We found that these two categories accurately captured the nature of all resident and staff interactions within the facility.

    - The first is between residents and COs or other staff (e.g., meal service providers, tablet and educational material providers, reentry coordinators, and legal call providers) that are frequent and of shorter duration. It is important to note that all DC DOC staff are trained annually in the importance of Universal Precautions in order to prevent infection spread. Furthermore, these staff are naturally inclined to maintain sufficient social distance so as to prevent body contact, assault, or other such incidents.

[1] In practice, this is likely far riskier than how facilities actually operate; however, we chose this method to consider what might happen if a significant number of staff members were unavailable for duty and regular housing unit staffing could not be maintained. We subsequently found that having a significantly smaller staff pool (less than half the original size) from which to randomly select staff to supervise the housing unit being simulated did not significantly alter findings. We believe, therefore, that insights will translate well to jail operations with fewer staff members.

  - The second is between residents and staff such as case managers, investigators, and medical service providers, which are less frequent but of longer duration (20–30 minutes of contact) and may involve brief durations when materials such as paperwork are exchanged (involving close contact).

- We considered limited mitigation policies. We assumed a 14-day quarantine period (no contact but medically monitored) for any staff or resident who showed symptoms, and a 14-day isolation period (no contact and medically supervised) for any resident who tested positive for the virus. We did not include impacts of contact tracing efforts, quarantine, and regular or reactive virus testing aside from intake testing in the simulations.

INPUTS

The inputs compiled for the SAFER-C™ scenarios were based on expert judgment and representative data from 2020 and 2021. The following subsections describe the types of parameters and data that were required to run the scenarios.

Model parameters

Epidemiological. Parameters describing the behavior of the virus were based on CDC mathematical modeling guidance (CDC, 2020b). The progression of symptoms shown in Figure 2 (page 7) was determined using a triangular distribution for each infected individual. The branching junctions (noted by the yellow boxes with triangles) were determined using probabilities based on CDC age groups. We did not include the effect of co-morbidities in the resident populations on the behavior of the virus.

AGE GROUPS CONSIDERED

18-49

50-64

65-74

75+

Because community spread is the primary means by which an infection enters a facility, the external contacts by staff as well as intakes were assumed to be infected at a rate equal to the test positivity rate (5.8%) of the city-wide DC COVID-19 statistics (DC Health, 2021a). It was assumed that this value stayed constant throughout the simulation period; this was a conservative assumption, because vaccination efforts would likely reduce the rates.

TRANSMISSION PROBABILITIES

LOW: 1.0%

NORMAL: 2.0%

HIGH: 2.5%

For each close contact, a transmission probability would determine whether an individual would become infected. Probabilities for low, normal, and high levels of transmission were defined, and a transmission probability was assigned for each activity based on expert judgment (e.g., pat-downs and searches had a high level of transmission while mail handoff had a normal level). While transmission rates are difficult to estimate and are based on environment, these values were assumed based on a range of data reported in literature studies (Chu et al., 2020; Otto, 2020).

Vaccination. We incorporated the effect of fully vaccinated and partially vaccinated individuals, assuming a two-dose administration. Vaccine efficacy was assumed to be 50% after 21 days and 94% after 35 days, using linear interpolation for the days in between (CDC, 2021). In addition, 22.3% of external individuals (i.e., intakes or volunteers) were assumed to be fully vaccinated and 14.0% were assumed to be partially vaccinated, following current DC area rates (DC Health, 2021b). Based on DC DOC facilities, approximately 33% of staff and residents were fully vaccinated while 10% were partially vaccinated. Vaccination status was randomly assigned at the beginning of each iteration of the simulation. It was further assumed that the maximum threshold for vaccination of the staff and resident populations, separately, would be 50% with up to 2 new vaccinations for staff and up to 20 new vaccinations for residents per day.

Intakes and releases. Jails have much more frequent movement in and out of the housing unit than prisons do. To capture the large number of intakes and releases experienced by jail facilities, we assumed a triangular distribution for the daily turnover rate. The net population stayed at 100 residents, but the turnover was between 5 and 25 (most likely 12) individuals per day, based on historical records. In addition, per DC DOC policy, testing was conducted for intakes the day they arrived at the housing unit as well as seven days after arrival.

Jail population data (includes residents and staff)

Resident data. Resident data were based on a de-identified, stratified sample of attributes of 1,942 residents in custody from March 2020 through December 2020. Age information was included in order to characterize the initial 100 residents and subsequent intakes. The residents were randomly assigned to one of two groups in the housing unit. The starting population and subsequent intakes and releases were randomly selected from this pool of residents for each iteration of the simulation.

Staff data. Only staff with direct contact were considered in the simulations. Some of these staff (e.g., COs) had frequent, close contact with residents, while others (e.g., case managers) had occasional prolonged interaction with residents. De-identified information was compiled for 892 staff based on historical DC DOC records, which include the age range of the staff and their roles and activities[2].

In addition, SAFER-C™ considers the need for substitution of certain staff (e.g., COs and security) who are isolating or otherwise out of the office. It was assumed that 10% of staff would be out for reasons unrelated to COVID-19. Staff unavailable for work on a given day were replaced with randomly selected staff of the same type on that same day.

TYPES OF STAFF CONSIDERED

Corrections Officers (COs)
Security
Investigators
Case Managers
Library Staff
Mail Staff
Maintenance Staff
Medical Staff
Administration

[2] The de-identified staff member data included estimated age ranges and did not include actual ages as this information was not available. Age ranges were estimated based on historical age data and years of service for the staff member cohorts.

Activity data

The final set of inputs required for SAFER-C™ includes detailed information for each activity in the housing unit that was modeled (see Table 1 on next page). The inputs collected in this step drive much of the simulation, so we strived to provide best estimates based on expert judgment at DC DOC. In general, the information that SAFER-C™ requires for each activity includes the following:

- Frequency of the activity
- Types of staff and COs that supervise or instruct these activities
- Types of residents that participate in these activities (note that the residents may be cohorted by half housing unit and/or group size may be limited)
- Number of external individuals that participate in these activities
- Number of individuals that attend each activity
- Estimated number of contacts that an infected individual (staff or resident or visitor) would have with other individuals (staff or resident) attending the activity
- Probability of virus transmission during the activity (low, normal, high)

Triangular distributions were used to assign activity parameters to account for uncertainty in staff and resident behavior. The parameters for the triangular distribution associated with each activity were estimated using practitioner input regarding the relative minimum, maximum, and most likely risk of transmitting virus during contact associated with that activity. Riskier activities were assigned higher relative risk parameter values. In addition, practitioner input was used to specify daily frequency and number of individuals for each activity. The specific individuals for whom close contact occurs are selected randomly from the activity event in the simulation. A total of 23 activities were defined for this analysis, as summarized in Table 1.

Table 1. Summary of activities

Activity	Transmission Probability	Frequency	Resident Participation	Description
Care - Chronic	Normal	Daily	33%/Day	By appointment, the resident is seen by a medical staff located outside the unit.
Care - Sick Call	Low	Daily	10%/Day	For minor issues, a medical staff is escorted by a CO to individual cells.
Care - Urgent	Normal	Daily	1%/Day	For major issues, the resident is seen by a medical staff located outside the unit.
Delivery - Commissary	Normal	2x/Week	30%/Day	A CO hand delivers commissary items to the individual residents in their cells.
Delivery - Mail	Normal	3x/Week	12%/Day	Mail staff hand delivers mails to individual residents in their cells.
Cell Maintenance	High	2x/Week	15%/Day	Maintenance staff perform repairs in individual cells.
Tablet Use	Normal	Daily	100%/Day	Staff distribute, collect, and sanitize tablets from residents in their cells.
Haircare	Normal	Weekly	5%/Week	By appointment, residents have a 15-20 minute visit with the barber and supervising CO.
High Contact Activities[a]	Very High	2x/Week	40%/Time	Groups of 10 residents play contact basketball during recreation time.
Staff Interaction - COs	Normal	Daily	---	This accounts for random close contacts among COs (e.g., at breaks or working).
Staff Interaction - All	Normal	Daily	---	This accounts for random close contacts among staff (e.g., at breaks or working).
Laundry Exchanges	Low	3x/Week	100%/Week	A CO distributes laundry bundle to individual residents through cell slot.
Library Visits	Low	Daily	2%/Day	Residents visiting the library have little interact with library staff on duty.
Materials Handling	Normal	Daily	---	The materials handler will meet with COs once per day.
Medical Distribution	Low	Daily	32%/Day	To distribute medication, a medical staff is escorted by CO to individual cells.
Medical Observation	High	Daily	3%/Day	To observe use of medication, a medical staff is escorted by CO to individual cells.
Misc. Administration	High	Daily	10%/Day	Miscellaneous staff (e.g., grievance coordinator) will meet with a resident at a desk.
Monitoring Specialist	Normal	Daily	---	Monitoring specialist comes into contact with lieutenants and captains once per day.
Movement	High	Daily	10%/Day	For out-of-unit appointments, residents meet other residents and staff in hallways.
On-Unit Work Detail	High	2x/Day	10%/Day	Groups of 3-5 residents work and take breaks together under CO supervision.
Out-of-Cell Time[b]	High	Daily	100%/Day	This includes any recreation activities (e.g., TV time, showers, and phone calls) that are not high contact. Residents interact in groups with others in their half housing unit.
Pat-Downs & Searches	High	2x/Day	100%/Time	This occurs in the AM and PM shifts with one of the 3-4 COs assigned during the shift.
(Re)Classification	High	Daily	10%/Day	A resident sits across a desk from a case manager upon intake or prior to release.

Source: DC DOC interviews.

[a] Only considered in high-contact scenarios. In addition, the estimated number of close contacts for out-of-cell time was increased if high-contact activities were allowed during recreation, to account for the increased level of engagement from residents when watching contact sports.
[b] The number of residents allowed out of cell at one time were varied in the scenarios.

PHASE 1: INITIAL ANALYSIS

Our initial analysis represented the housing unit operations and activities in a restricted status. Non-essential programs—including classes, volunteer activities, and most work programs—were halted. Out-of-cell time for residents was limited in duration and group size so that only 10 residents were allowed on the floor at the same time. High-contact activities (e.g., basketball) and in-person visits were halted. The initial analysis allowed virus transmission from the introduction of an individual with an undetected infection into the housing unit and from staff via community spread.

The results of the initial analysis simulations were found to relate well to the on-the ground experience of practitioners. We then proceeded to consider the impact of reopening activities and evaluated the effect of alternative reopening scenarios. Based on a discussion of the results of those simulations with DC DOC's medical director, colleagues at DC Health, and DC DOC's health service provider, we recalibrated the initial analysis to form a baseline and develop additional scenarios.

PHASE 2: MODELED SCENARIOS

In the second phase of the analysis, we executed a Baseline case (recalibrated from the initial analysis) as well as eight scenarios. The Baseline case assumes the following:

- 40 residents simultaneously out of cell for recreation
- An initial fully vaccinated rate of 33% for staff and residents
- A single, random seeded infectious individual in the housing unit

Using the Baseline case as a reference, we explored three effects in the scenarios: out-of-cell group size, vaccination rate, and high-contact activity resumption. Each scenario was run for 10,000 iterations to capture the range of outcomes for the simulations.

Effects of out-of-cell group size

The CDC recommends that correctional facilities limit resident interaction with those in their same housing unit or cohorts, to help mitigate the spread of COVID-19 at the facility (CDC, 2020a). Thus, the residents in our simulations were assigned to one of two groups in the housing unit, and they were released for recreation in those cohorts. Under normal circumstances, the entire half housing unit of 40 residents (Baseline case) is released out of cell at the same; however, during the pandemic, this number has been limited to 10. Thus, we evaluated the effect of increasing the group size from 10 to 20 to 40 residents from the same half housing unit. We assumed that the estimated number of close contacts per individual would increase proportionally with group size.

Effects of vaccination rate

At the time of writing, the COVID-19 vaccinations were readily available to correctional facilities and the general public. Thus, we were interested in understanding the effect of higher rates of vaccination. We evaluated cases where 33% (Baseline case), 50%, and 70% of the staff and residents were fully vaccinated.

Resumption of high-contact activity

High-contact activities were halted during the COVID-19 pandemic because of the additional risk of bodily interactions from playing five-on-five basketball, board games, etc. However, these activities are popular among residents and may be considered for reopening. For these high-contact activity scenarios, we assumed that the transmission probability in these activities would be "very high" at 5% (as opposed to "high" at 2.5%).

We evaluated four scenarios involving high-contact activities, to evaluate the level of risk with higher vaccination rates and greater initial infection. The vaccination rates were varied, to provide insight into allowing reopening only with higher rates of vaccination. A scenario with five infected residents versus one infected resident was also evaluated, to provide insight into whether and/or how high-contact activities would propagate an outbreak.

Table 2 gives a summary of the scenarios conducted in the second phase of the analysis.

Table 2. Summary of scenarios and simulations run

<table>
<tr><th>Scenario</th><th>Simulation Name</th><th>Out-of-Cell Group Size</th><th>Initial Vaccination Rate</th><th>High - Contact Activity</th><th>Initial Infection Seed</th></tr>
<tr><td>Baseline</td><td>Baseline</td><td>40</td><td>33%</td><td>No</td><td>1</td></tr>
<tr><td rowspan="2">Reduced Out-of-Cell Group Size</td><td>Group_10</td><td>10</td><td>33%</td><td>No</td><td>1</td></tr>
<tr><td>Group_20</td><td>20</td><td>33%</td><td>No</td><td>1</td></tr>
<tr><td rowspan="2">Increased Vaccination Rates</td><td>Vac_50</td><td>40</td><td>50%</td><td>No</td><td>1</td></tr>
<tr><td>Vac_70</td><td>40</td><td>70%</td><td>No</td><td>1</td></tr>
<tr><td rowspan="4">Reintroduced High-Contact Activities</td><td>High</td><td>40</td><td>33%</td><td>Yes</td><td>1</td></tr>
<tr><td>High_70</td><td>40</td><td>70%</td><td>Yes</td><td>1</td></tr>
<tr><td>High_5</td><td>40</td><td>33%</td><td>Yes</td><td>5</td></tr>
<tr><td>High_70_5</td><td>40</td><td>70%</td><td>Yes</td><td>5</td></tr>
</table>

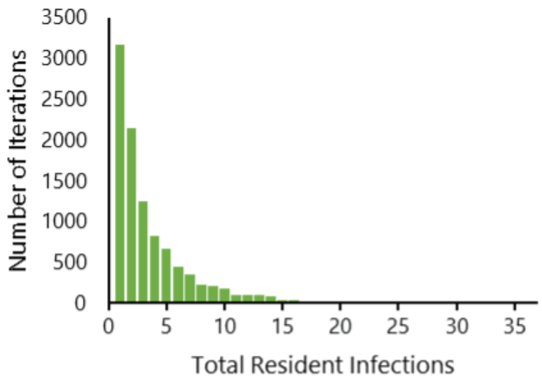
Source: CNA.

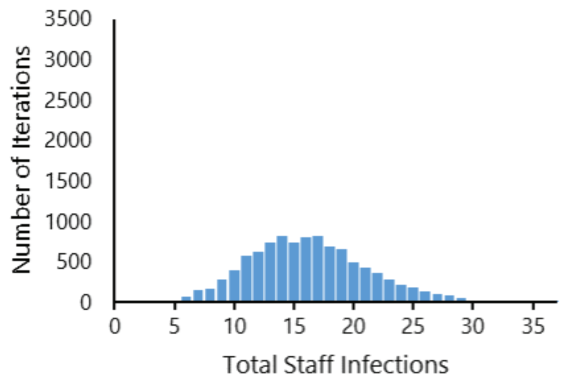
RESULTS

BASELINE CASE RESULTS

For the Baseline case, we found that the average number of infections (asymptomatic and symptomatic) among residents was 3.6 cases, up to a maximum of 29 cases. Note that, due to daily intakes and releases, approximately 450 residents would enter the housing unit during the 25-day period. For staff, an average of 16.3 out of a total of 892 staff members were infected, up to a maximum of 37 cases. However, an average of 12.8 of those infections came from contact outside the housing unit while the remainder were from interactions within the unit. Out of all 10,000 iterations of the Baseline case, 2% reported one resident fatality, while one iteration reported two fatalities. For staff, 19% of iterations reported one fatality; 2%, two fatalities; and 0.1%, three fatalities. Figure 3 depicts the range of infections found in the 10,000 Baseline iterations. We observed that there was a larger range of total staff infections compared to resident infections because of the opportunity for each staff member to be infected outside the housing unit each day.

Figure 3. Range of resident (left) and staff (right) infections for Baseline case

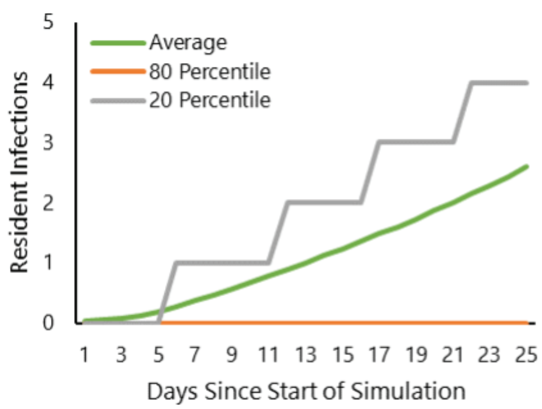


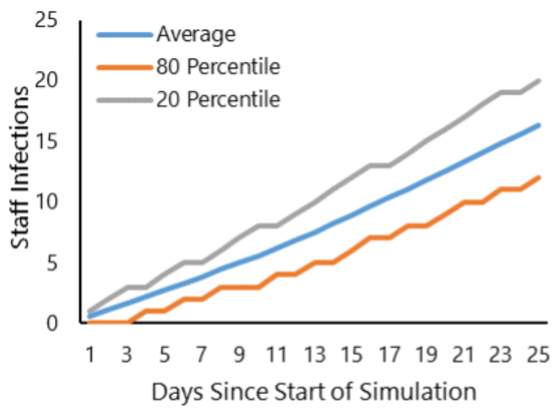


Source: CNA.

Over the 25-day period, we found that the infection rate was fairly steady for the staff, with an average of 0.7 new cases per day, increasing from 0.5 new cases on day 1 to 0.8 cases on day 25. This pattern is likely due to the cumulative effect of community spread and staff-to-staff interactions on the staff population. The infection rate for residents was less consistent and generally increased over time, from 0.03 to 0.2 new cases per day. Figure 4 shows the overall trends in cumulative infections for both residents and staff over the 25-day simulation period.

Figure 4. Cumulative infections among residents (left) and staff (right) for Baseline case

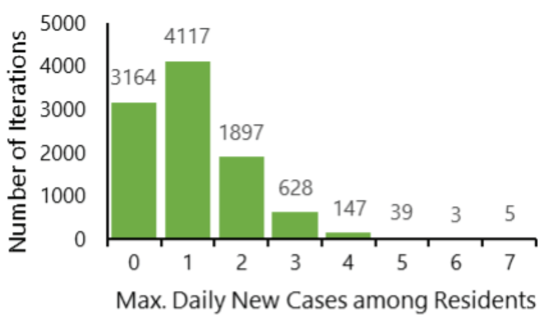


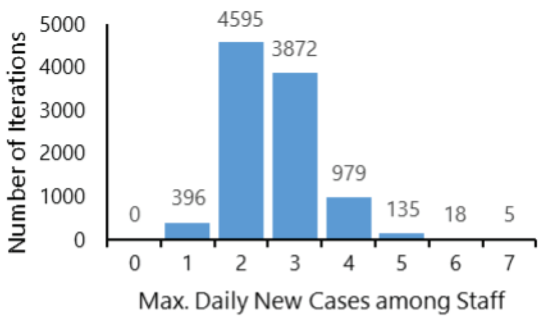


Source: CNA.

We also recorded the maximum number of new cases on any given day. These values may be useful in helping predict any strains on facility resources in dealing with outbreaks. Figure 5 shows a histogram of the maximum new cases: 0-1 for residents and 2-3 for staff, with up to a maximum of 7 new cases in a single day for both populations.

Figure 5: Range of maximum daily new cases among residents (left) and staff (right) for Baseline case





Source: CNA.

Throughout the course of the simulations, we assumed that no changes to housing unit operations or policies were made, regardless of the number of infections that were detected at the housing unit. The only reactive mitigation considered was a mandatory isolation of any staff or resident who showed symptoms. We observed that in 83% of iterations, there was at least one staff out (i.e., in isolation) with a maximum of nine staff out on any given day. For residents, we observed that at least one resident was isolating in 30% of iterations, with a maximum of six residents on any given day.

Due to the detailed nature of SAFER-C™, we are able to observe trends in the specific activities simulated. From an operational point of view, identifying potential hotspots and most-at-risk pathways to virus spread is a key benefit of the tool. Table 3 presents a summary of infections resulting from each activity as a whole and by each population for the *Baseline* case.

Table 3. Summary of infections from all activities in the Baseline case (sorted by Average)

Activity	Max.	Avg.	Std. Dev.	Prevalence[a]	Total Infections From[b]		
					Staff	Residents	External
Community Spread	**28**	**12.8**	**3.5**	**100%**			
Staff Interaction - COs	**12**	**2.1**	**1.8**	**82%**	**21,360**		
Out-of-Cell Time	**27**	**1.5**	**2.9**	**37%**		**15,302**	
Staff Interaction - All	**8**	**1.1**	**1.1**	**62%**	**10,685**		
Pat-Downs & Searches	**15**	**0.6**	**1.1**	**32%**	**4,131**	**1,785**	
Movement	**6**	**0.6**	**0.8**	**43%**	**15**	**280**	**5,541**
Care - Chronic	3	<0.1	0.4	4%	292	181	
Tablet Use	3	<0.1	0.2	4%		386	
Monitoring Specialist	3	<0.1	0.2	2%	273		
Materials Handling	4	<0.1	0.2	2%	200		
Laundry Exchanges	2	<0.1	0.1	2%	167	28	
Haircare	2	<0.1	0.1	2%	5		164
(Re)Classification	3	<0.1	0.1	1%	95	32	
Sick Call	2	<0.1	0.1	1%	101	15	
Medical Distribution	1	<0.1	0.1	1%	11	98	
Delivery Mail	2	<0.1	0.1	<1%	52	14	
On-Unit Work Detail	1	<0.1	0.1	<1%		53	
Medical Observation	2	<0.1	0.1	<1%	21	18	
Delivery - Commissary	1	<0.1	0.1	<1%	20	15	
Misc. Administration	1	<0.1	0.1	<1%	27	7	
Cell Maintenance	1	<0.1	<0.1	<1%	11	13	
Care - Urgent	1	<0.1	<0.1	<1%	4	6	
Library Visits	1	<0.1	<0.1	<1%	2	1	

Source: CNA.

[a] The percentage of iterations that recorded at least one infection from this activity.

[b] The total number of infections transmitted from staff, residents, and external individuals to others during this activity in all 10,000 iterations. The shading reflects the relative number of infections as compared to others.

The activities in Table 3 are listed in order of decreasing average number of resulting infections. The first six activities have infection rates that are significantly higher than the lower-ranking 17 activities.

- **Community spread** is found to be the leading cause of infections entering the housing unit and contributing to the majority of staff infections, on average. The simulation considers the possibility of infection from two outside close contacts for each of the 892 staff each day. This is the only activity for which we observed 100% of iterations having at least one associated infection.

- The two **staff interactions (all and COs)** are the only activities aside from community spread that had relatively consistent infection rates across the iterations. This is indicated by the fact that the standard deviations for their infection rates were lower than the average. The infections from staff interactions are based on highly random interactions from large staff pools, which results in more consistent rates.

- The infections from **out-of-cell time** and **pat-downs and searches** are the highest ranking activities that involve interaction between staff and residents. Interestingly, while the average infection rate of the activities is similar to or lower than that for staff interactions, the maximum infection rate observed is higher (i.e., 27 and 15 versus 12 and 8). The percentage of iterations that had at least one infection from these activities is also disproportionally lower than it is for staff interactions (i.e., 37% and 32% versus 82% and 62%). These discrepancies are caused by the fact that the out-of-cell time and pat-downs and search activities are at higher risk of causing outbreaks. While community spread and staff interactions typically result in random infections throughout the staff pool, the out-of-cell time and pat-downs and searches have more targeted pools. For example, one infected CO conducting pat-downs and searches comes into direct contact with many residents during their shift. For out-of-cell time, one infected resident comes into contact with many of the same residents in their recreational group of 40 each day, increasing exposure and propagating the infection more quickly.

  The simulation results also suggest that staff are 2.3 times more likely to be infected by pat-downs and searches than residents. This could occur because staff members may be exposed to sufficient cumulative levels of viral particles over the course of a series of searches that cause infection. An example of this is when officers pat down and search a vanload of residents returning from court or clinic visits, where seating areas and other surfaces may result in exposure to viral particles. The virus may cling to residents' clothing and be released into the air during the pat down process. Individual residents are at lower risks during pat-downs particularly if the particles are only lodged on their clothing and they are donning masks correctly.

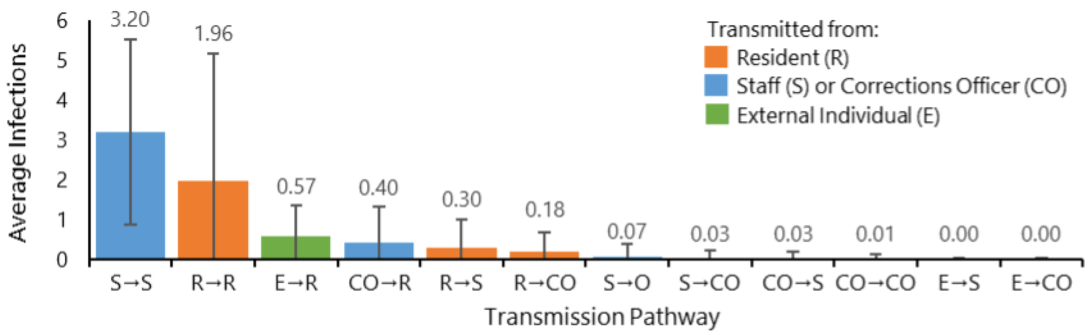
- The **movement** activity includes interaction with external individuals (e.g., residents of other housing units, education providers, or volunteers) who are assumed to be infected at the same rate as that prevalent in the community. This is similar to that of community spread—which, instead of affecting staff, directly affects residents.

The remaining 17 activities have significantly lower average infection rates and frequencies than the top six. Only up to 4% of all iterations resulted in at least one infection independently from each of these activities. However, based on the outbreak effect seen with out-of-cell time and pat-downs and search activities, it may be possible for an infection transmitted during a less risky activity to trigger an outbreak during riskier activities.

In addition to analyzing the infection rates by activity, we also evaluated the infection rates by types of staff. The three staff groups with the highest average number of infections were COs (13.4), administration (e.g., information technology support) (0.9), and investigators (0.79). However, normalized by the total number of staff of the respective group, the highest average infection percentages were maintenance (10.7%), case managers (4.1%), and security (2.8%). The percentage of COs infected (1.8%) may be underestimated because COs would also be exposed to possible infection at other housing units that were not simulated in this analysis. However, it is also true that COs are trained in Universal Precautions and practice these when interacting with residents. They also routinely maintain social distance during normal day-to-day interactions with residents to avoid possibility of direct contact or assault. The high average number of infections among COs is from high exposure to particulate matters in the course of routine activities over the cumulative duration of a shift; for information technology support staff - exposure to accumulated particulate matter on high touch surfaces in restricted office areas where occupants operated without masks, and investigators who had relatively close contact for relatively long durations.

We also evaluated the average infection rate of different transmission pathways. In Figure 6, virus transmitted to and from COs are shown separately from non-uniformed staff, and community spread is not included. The pathways with highest average infection rates are from staff-to-staff and resident-to-resident interactions. As seen in Table 4, these pathways are prominent in the top-ranking activities (i.e., staff-to-staff infections in staff interactions and resident-to-resident interactions during out-of-cell time). Of note is that the pathway with the third-highest average infection rate is from external providers to resident. This occurs during haircare activities, services and programs facilitated by an external provider or volunteer, and visiting; most of these involve movement out of the housing unit.

Figure 6. Average housing unit[a] infections by transmission pathway for Baseline case



Source: CNA.

[a] Infections from daily outside contacts (i.e., community spread) to staff are not included.

Finally, we calculated the basic reproduction rates (R0) of the virus. The average R0 value for infected staff was 0.22 (i.e., each infected staff member on average transmitted the virus to 0.22 other staff and residents), while the average R0 value for infected residents was 0.32. The R0 values are not comparable to community values, because of the restricted operations and movement in a closed facility, such as a jail. The fact that the R0 is less than 1 indicates that, were the facility completely closed, the number of infections would eventually decline and disappear. Thus, in most iterations of the *Baseline* case, the number of infections is driven by outside infection (i.e., community spread) rather than internally propagated transmission.

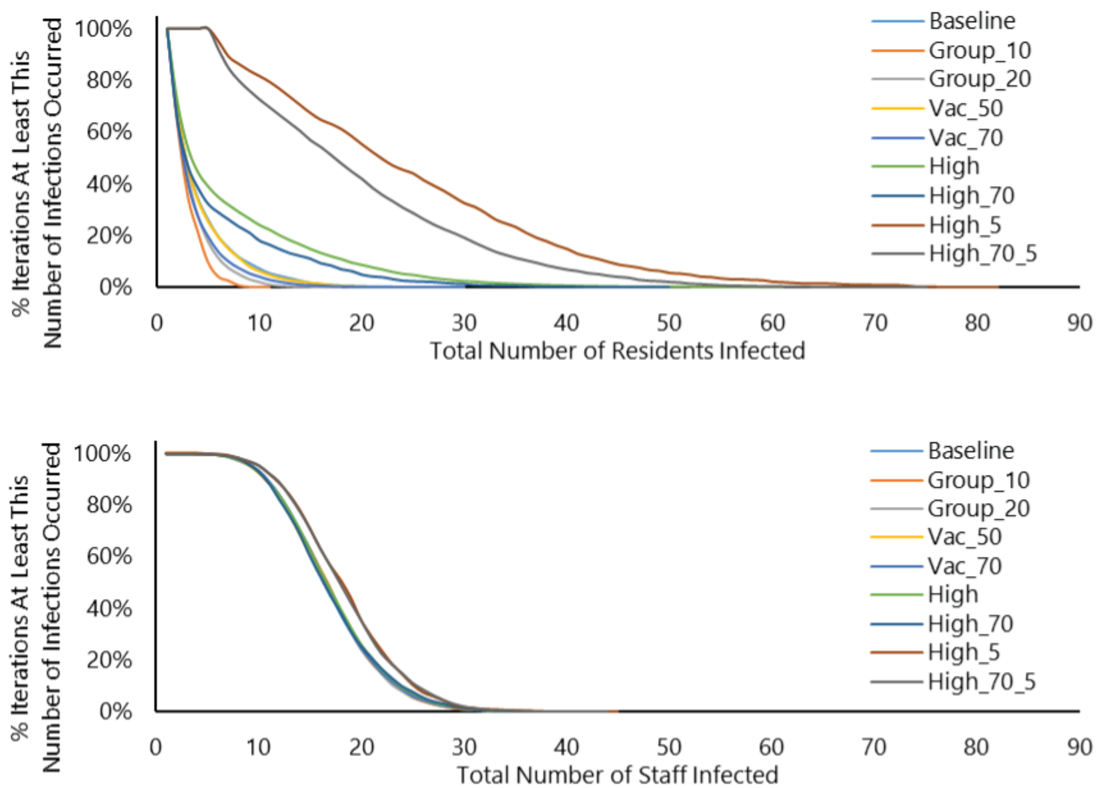
MODELED SCENARIOS RESULTS

In the eight scenarios, we investigated three main effects on the *Baseline* case.

1. We subsequently explored the consequences of changing the group size allowed out of cells simultaneously from a baseline of 40 to 20 (*Group_20*) to 10 (*Group_10*) residents.
2. We explored the impact of progressively higher vaccination rates among residents, starting from a baseline rate of 33% of residents and staff, subsequently increasing to 50% (*Vac_50*) and 70% (*Vac_70*).
3. We also explored the impact of reintroducing high-contact activities (*High*) with the *Baseline* scenario and then simulated the impact of a 70% vaccination rate among residents in addition to that case (*High_70*). We also simulated what might happen if upon reintroducing high-impact activities with 40 residents simultaneously out of cell, five individuals were introduced into the housing unit simultaneously with undetected infections (*High_5*), and what might change in that case if 70% of residents were vaccinated (*High_5_70*).

Figure 7 shows a summary of the resident and staff infection ranges observed for 10,000 iterations of each of the eight scenarios.

Figure 7. Range of resident (top) and staff (bottom) infections for all scenarios



Source: CNA.

The resident graph shows three stratifications based on overall infection trends: the highest are the five-seeded scenarios (*High_5* and *High_70_5*), followed by the one-seeded scenarios with high-contact activities (*High* and *High_70*), and finally the remaining scenarios (*Group_10, Group_20, Vac_50, Vac_70,* and *Baseline*). The jump between the one- and five-seeded scenarios is caused by the extra four infections that are introduced at the beginning of the simulation. The five-seeded scenarios have a beginning plateau because 100% of iterations of the *High_5* and *High_70_5* scenarios now have a minimum of five infections. The one-seeded scenarios have no plateau, and all show a sharp drop at the beginning of the graph. This implies that most iterations (~80%) had only one or a few total cases, with the high-contact activity scenarios reporting a slightly higher number of cases. Conversely, the slopes of the five-seeded scenarios are more gradual and constant, showing that the iterations simulated varying levels of outbreaks.

The staff graph in Figure 7 shows only two stratifications separating the one-seeded and five-seeded scenarios. The data indicate that the staff infection ranges do not vary widely among the scenarios as opposed to the resident infection ranges. This lower variability in the staff infections is due to the fact that community spread, whose assumptions remain unchanged in all scenarios, accounts for the majority of the staff infections and thus remains fairly constant throughout all scenarios. In addition, most of the scenarios directly affect resident interactions (e.g., higher resident-to-resident transmission rates in contact activities and more resident-to-resident contacts as out-of-cell groupings increase) rather than staff interactions. We also found that, while the five-seeded scenarios show slightly higher infection rates, the lines converge again around a maximum of 30 infections. There is a plateau at the beginning of all the scenarios indicating that more than 90% of all iterations reported at least 10 staff infections. The slopes of all lines are constant, likely because of the constant potential of community spread infection in all scenarios for staff.

A statistical summary of the infection results for each scenario is shown in Table 4. In general, the maximum and percentile values are useful in understanding the range of outcomes of the simulations. As a probabilistic model, SAFER-C™ relies on random draws, which represent uncertainties in individuals' behaviors in a jail facility. The maximum values in Table 4 show "worst-case" infection rates when outbreaks occur. The 80th percentile metrics can tell us how likely these types of more severe situations are to occur.

Table 4. Summary of infection results from all scenarios for residents and staff

Scenario	Resident Infections					Staff Infections				
	Min.	Max.	Avg.	P_{20}[a]	P_{80}[b]	Min.	Max.	Avg.	P_{20}[a]	P_{80}[b]
Baseline	1	29	3.6	1	5	1	37	16.3	12	20
Group_10	1	10	2.4	1	4	4	41	16.3	12	20
Group_20	1	17	2.9	1	4	1	40	16.4	12	20
Vac_50	1	25	3.5	1	5	2	42	16.3	12	20
Vac_70	1	23	3.0	1	4	0	42	16.4	12	20
High	1	60	6.6	1	12	3	38	16.5	12	21
High_70	1	49	5.3	1	9	4	36	16.4	12	21
High_5	5	81	23.9	10	36	3	44	17.8	13	22
High_70_5	5	74	19.0	7	29	3	43	17.7	13	22

Source: CNA.

[a] The minimum numbers of infections present in the 20th percentile (P_{20}) of iterations; in other words, at least this many infections occurred in 80% of the iterations.

[b] The minimum numbers of infections present in the 80th percentile (P_{80}) of iterations; in other words, at least this many infections occurred in 20% of the iterations.

As expected from the graphs in Figure 7, the staff results for all scenarios in Table 4 are very similar to each other while the resident results differ greatly. The maximum staff rates are no more than twice that of the 80th percentile values while the resident maximum rates are between 2 and 8 times higher than the 80th percentiles. As a result, the tails of the range of outcomes for the resident infection rates are longer and the severity of propagating outbreaks is much higher than the average number of infections that may result if the "worst-case" virus transmission conditions occur.

Results of variations in out-of-cell group size

The *Group_10 and Group_20* scenarios showed similar results, and the range of infection rates did not vary between groupings of 10 and groupings of 20 residents. While there is a slight increase in average number of infections (2.9 to 3.6) to the *Baseline* case (groupings of 40), the maximum number of cases reported increases more notably, from 10 to 17 to 29, for increased group sizes. This implies that decreasing the group size may help reduce the number of more severe but less likely outbreaks. It also implies that in facilities requiring 14 days of intake quarantine prior to introducing persons known to have tested negative for SARS-CoV-2 into housing units, there is a marginal increase in risk of infection transmission associated with increasing out-of-cell group sizes to the *Baseline* level, provided that interactions with case managers or other staff are limited and conducted in a masked and socially distanced manner.

Results of variations in vaccination rate

The *Vac_50 and Vac_70* scenarios also did not show much difference, except in cases where higher starting rates of vaccination were coupled with reintroducing high-contact activities (*High_70 and High_70_5*) in mixed groups of vaccinated and unvaccinated residents. We observed that, while the initial proportion of fully vaccinated residents was increased to 50% or 70%, the proportion of fully vaccinated residents over the 25-day period dropped below 40% by day 5 of the simulation. This is because new facility intakes were assumed to have a vaccination rate equal to that of the community vaccination rate at that time (i.e., 22.3% fully and 14.0% partially vaccinated). Thus, with an average turnover rate of 15 residents each day in the housing unit, the proportion of fully vaccinated residents quickly declined.

Despite experiencing an eventual drop in vaccination rates, the scenarios with higher vaccination rates did indicate some reduction in cases. In particular, the scenarios with high contact activities (*High_70 and High_70_5*) saw a reduction in both the average and maximum number of cases when a 70% vaccination rate was considered. Interestingly, at a 70% vaccination rate there was actually one iteration for which the total number of staff infections was zero. In this rare instance, no community spread was experienced by the staff and the high vaccination rate at the housing unit prevented the virus from spreading from the initial infected resident.

Results of resuming high-contact activity

We observed that the scenarios with the highest overall infection rates were those considering high contact activities. When only one infection seed is considered, the 20th percentile of these scenarios still indicates only one case. However, if there is an outbreak, as shown in the 80th percentile of iterations, the outbreaks can be more significant (9-12) with a maximum of up to 60 cases. In practice, facility infection control protocols would be implemented as soon as the first positive case is detected, making it unlikely that an outbreak reaches this point. The virus may, however, still spread; facilitated by fully vaccinated persons who are infected. These persons may remain asymptomatic while carrying substantial viral loads, allowing transmission to occur undetected for some time before quarantine protocols are implemented.

The scenarios with the highest overall infection rates in this analysis were those that considered both five starting infections and high-contact activities (*High_70_5 and High_5*). With the baseline vaccination rate, the average infections jump from 6.6 cases to 23.9 cases and the maximum number of cases from 60 to 84 cases. While high vaccination rates can dampen this effect, the combination of a higher number of initially infected persons and high-contact activities leads to a higher likelihood of propagating outbreaks.

OTHER RESULTS

In addition to the *Baseline* and eight scenarios, two limited additional scenarios were also considered, in order to evaluate the sensitivity of major assumptions made in the analysis. It was assumed that intakes were quarantined before entering the housing unit, which we considered in the model by assigning all intakes as not infected. To evaluate this assumption, we ran a limited simulation (2,500 iterations) of a modified *Baseline* case that assumed intakes were not quarantined and were able to interact immediately with other residents. The intakes were assumed to be infected at a rate equal to the community rate of infection. We found that the average infection rates were 31.0 (maximum 60) for residents and 18.4 (maximum 40) for staff. In 18.7 of the resident cases, the intakes themselves were infected before entering the housing unit. While the staff infection rates remain similar, the resident infection rate increased significantly from the *Baseline* average of 3.6 (maximum 29).

The second limited scenario assessed the effect of reducing the size of the overall staff pool. In the previous scenarios, the staff pool was assumed to be for the entire facility and randomly assigned to the housing unit each day. To test this assumption, we ran a modified *Baseline* case that considered only a quarter of the staff pool (i.e., 219 individuals), retaining the original proportions of the staff types. We found that the average infection rates were 3.7 for residents and 7.4 for staff (1.8 being from outside contacts). Thus, the resident infections were similar to the *Baseline* case while the staff cases were proportionally higher (i.e., 3.4% vs 1.8%). This is expected, because of the increased frequency at which members of the small staff pool now interact with each other and with other residents. Thus, facilities with smaller staff pools and higher levels of potential interaction among staff may be at higher risk for infection among staff than larger facilities with larger staff complements. It is worth reiterating that the simulation (as well as on-the-ground experience) suggests that staff are most at risk of infection through community spread and staff-to-staff interactions, and that unless staff are engaging in prolonged contact activities with residents, residents are most at risk of infection from contact with other residents or external agents.

DISCUSSION

INSIGHTS

The *Baseline* case and scenarios each generated a significant amount of output data from SAFER-C™. The *Baseline* case was developed and executed first to evaluate whether the outcomes were reasonable and reconciled with on-the-ground practitioner knowledge. Only after the Baseline case was validated were the scenarios developed and executed. As with any stochastic ABM, the inputs to the tool are crucial and must be generated with subject matter experts and sufficient data. As such, SAFER-C™ required CNA to work closely with DC DOC staff to collect accurate inputs and formulate appropriate scenarios. Other efforts to model disease spread, such as Hunter and Kelleher (2021), have also emphasized the need to tailor input parameters to best represent the model context.

The results of the model closely aligned with DC DOC’s observations during the early days of the pandemic, especially with respect to the maximum number of observed resident and staff infections per day, the categories of staff most likely to be infected, and the number of infected staff observed during a 25-day period. Our results found that staff-to-staff and resident-to-resident transmissions were the most prominent—corroborating DC DOC’s actual experience. Correctional staff are all trained in universal and COVID-19 health and safety precautions. COs also naturally tend to stay at least four to six feet away when interacting with residents to avoid any unprompted harmful behavior. Furthermore, many staff are also conscious of the risk of transmitting infections from the community to the residents and from residents to their families. However, staff have been known to be less guarded in their interactions with other staff, particularly when working overtime assignments in areas not previously known to be at high risk for infection. These behaviors have been reflected both in the results of the analysis and in internal agency analysis of infection transmissions among staff at DOC facilities. Internal agency analysis using independent methods have resonated with the results of the SAFER-C™ simulations. Similarly, internal agency analysis of resident infections has also resonated with the results of the SAFER-C™ simulations.

When we were adapting the model to DC jail facilities, DC DOC was considering policies for reopening. The results from the SAFER-C™ scenarios helped inform these decisions. For example, based on the insights from the simulations, activities involving movement outside of housing units, such as visitations and reintroduction of programs, are limited to residents and external persons who were known to be fully vaccinated. Out-of-cell group sizes continue to be guided by DC Health and CDC guidelines, despite simulation results indicating marginal increases in infection risk associated with out-of-cell group size alone. Group sizes continue to be limited by the concern that large group sizes are associated with higher risks of more severe outbreaks as suggested by the results of the simulations. The operational challenge remains how to productively engage residents in activities that limit risk of infection and allow for effective supervision to enforce social distancing and mask use, while allowing for increased out-of-cell-group sizes. High-contact activities are limited to those known to be fully vaccinated. Basketball has not yet been reintroduced, because of its high level of infection risk.

Once the initial reintroduction of normalized activities commenced, several residents decided that getting vaccinated was in their best interest and the daily numbers seeking a first or second dose of vaccine have increased. Residents began to see full vaccination status as a positive—a way to fully participate in out-of-cell activities once again, even if masked and maintaining social distance. The simulations have provided valuable insight in helping the facility leadership explain why the overall resident vaccination rate hovers around 36-37%, despite continued increase in participation in the vaccination program.

For staff, simulation results have supported other internal analyses which have suggested that staff performing certain job functions must comply with strengthened PPE requirements -such as gloves, use of N95 respirators, multiple layers of face coverings and/or face shields. These include staff performing facilities maintenance functions, pat-downs on a routine basis, high-movement activities that expose them to many areas of the facility and many correctional staff, or prolonged contact with residents or staff during daily activities—such as case managers who conduct assessments. Together with other infection control measures, acting on these insights can help maintain the health and well-being of staff.

The results discussed in this paper pertain to a generalized housing unit for a jail facility. While the inputs are based on DC DOC data, we attempted to generalize the facility operations and population sizes so that the insights gained from this analysis would be useful to other facilities. We believe that the questions in this white paper that concern reopening (e.g., vaccination rates and increased resident interaction) are questions that jails are facing nationwide. The range of outcomes presented in this white paper show not only the average or "most expected" outcomes from each of the scenarios but also maximum cases and "worst-case" scenarios that leaders must be prepared for. While our analysis addresses initial questions that jails may face, SAFER-C™ can be tailored to specific facilities and used to evaluate many more "what-if" scenarios.

LIMITATIONS

SAFER-C™ is a useful tool for estimating the effect of "what if?" scenarios for corrections facilities faced with the potential for or existing threat of virus spread in their staff and resident populations. It is intended to be a supplemental tool for corrections administrators—that is, other, traditional, decision-making methodologies should still be used in conjunction with it. The analyses in this white paper demonstrate the insights gained from using a detailed ABM based on realistic parameters and input data. While we describe major assumptions in the Methodology section, additional limitations of the model and its application to the scenarios are noted below.

- SAFER-C™ requires significant subject matter expertise and good parameterization. The output of the model is directly related to the inputs, and thus it is important to obtain accurate parameter estimates. The scenarios executed in this white paper required a great deal of detailed data from subject matter experts. As a result, a limited set of scenarios and activities have been considered. Other activities such as the restarting of classes and volunteer programs were not modeled at the time of writing.

- The scenarios reflect a more conservative set of assumptions and thus likely represent a higher level of risk than that encountered in reality (i.e., they are "worst case scenarios"). For example, they do not consider mitigation efforts, such as quarantining, which would realistically occur upon detection of the first infection. Activities were modeled constantly across all 25 days of the simulations regardless of the number of infections present at the housing unit.
- The scenarios developed for this white paper were based on actual DC DOC facilities and generalized to have a larger application. In particular, the staff complement for the facility was large and staff were randomly assigned to the unit for daily shifts, relief, and other activities. The assumption of random assignment of staff introduced higher risk than how DOC facilities actually operate. However, when staff outbreaks occur, this is not such a bad assumption. Many jails will have smaller complements and staff assignments will not be random. Furthermore, new intakes were cell restricted in the housing unit for 14 days. In larger jails, intakes are not cell restricted in housing units but rather in specialized intake units. However, many jails that hold 50-100 residents may actually be cell restricting within the housing area of the facility, so our model better represents their reality.
- SAFER-C™ was developed in 2020-2021 during the COVID-19 pandemic. The model was updated with CDC modeling parameters and existing literature at the time of analysis. Thus, the results represent the epidemiological inputs (e.g., vaccination rates and community spread) of a specific time period and localization. Parameters should be continually updated to reflect current knowledge and circumstances.

CONCLUSIONS

In this paper, we describe the use of SAFER-C™ to model various "what-if?" scenarios of concern to a representative housing unit of a jail facility considering the reinstatement of limited resident activities during a pandemic. We discuss the significant amount of detailed information required as inputs to SAFER-C™, an agent-based tool, to ensure that assumptions and activities are modeled correctly. We used subject matter expertise to collect representative data from DC DOC regarding epidemiological factors, resident and staff populations, and facility operations.

In our analysis, we identified activities and transmission pathways in the Baseline case that were most at-risk for virus transmission. The activities corresponding to the most average number of infections were community spread, staff interactions, out-of-cell time, pat-downs and searches, and movement of residents outside of housing unit. As a result, efforts can be focused to reduce close contact or the possibility of ill individuals participating in these high-risk activities.

In addition, we conducted eight other scenarios in order to evaluate the effect of increasing out-of-cell group sizes, changing vaccination rates, and reintroducing high-contact activities. Overall, we found that increasing group sizes and changing initial vaccination rate assumptions did not have notable impacts on the average infection rate. However, we did find that small group sizes may help lower the potential for larger outbreaks and that resident vaccination rates will be dictated by the vaccination statuses of intakes. Furthermore, higher vaccination rates did help lower infection rates when high-contact activities were considered. The reinstatement of high-contact activities caused the greatest increase in infections, especially when more infections are initially introduced into the resident population. This outcome stresses the importance of quarantining and testing intakes, which was supported in an additional analysis we conducted.

Overall, we believe that SAFER-C™ is a useful, quantitative tool for decision-makers managing policy responses to a pandemic. The agent-based approach to modeling in SAFER-C™ allows users to evaluate specific scenarios and their impacts on a facility's population. The detailed output from the tool also allows for insights such as identifying more vulnerable groups, detecting more risky activities, and understanding the effect of mitigation efforts. As jail facilities across the country are faced with unprecedented circumstances during the COVID-19 pandemic, quantitative tools such as SAFER-C™ are a valuable asset that can provide additional insights for correctional leaders.

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CIM-2021-U-030862

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