Potential COVID-19 Outbreak in Fire Camp: Scenario Analysis and Implications

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Key Points
• We adapted a peer-reviewed epidemiological model of COVID-19 to the context of a wildfire incident where the population changes over time
• We applied the model to population data from three historical wildfires to illustrate potential outbreak dynamics; results are not intended to be predictive
• We explored a range of hypothetical scenarios regarding infection rates, entry rates of infected personnel, and fatality rates, and how they may vary with risk mitigation strategies
• Limited testing, testing errors, asymptomatic cases, and possible failures of screening suggest the possibility of an infected individual arriving at a large fire incident; this could lead to a rapid outbreak with widespread infection
• Aggressive screening and testing (if it becomes available and advisable) to initially isolate infected individuals can reduce the total number of infections, but the benefits diminish as incident duration increases
• Aggressive social distancing measures (e.g., modular isolation, spike camps, increased use of telecommunications) are likely to be more effective at reducing the total number of infections
• Best case scenario assumes screening/testing and social distancing are implemented jointly and effectively, which may significantly reduce but not eliminate risk
• Results presented here are for individual incidents; effects may be compounded across multiple fires and may introduce systemic disruptions in capacity

About the Approach
This report is a dynamic document and will be updated throughout the fire season. The report is based on various scenarios. It is important to note that scenarios and model outcomes are not predictions. Instead, the purpose of this scenario analysis is to account for key uncertainties, to assist in creative thinking about novel situations, and to help identify robust decisions and actions that would be appropriate and effective across a range of potential future conditions. As such, the draft report is intended to help managers understand a range of possible conditions and outcomes that they can couple with real-time information to make risk-informed decisions.

Preliminary results - to be updated as more information becomes available
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Background

The wildland fire management community is developing guidance and planning modifications to wildland fire response strategies, operations, and logistics in order to mitigate the variety of risks posed by COVID-19 [1-3]. Further, responders are sharing lessons learned in the conduct of fire operations to better understand the considerations and consequences of putting COVID-19 mitigations into practice [e.g., 4-10]. One of the risks posed by COVID-19 is rapid outbreak of infection in a traditional large fire camp, where high-density living and working conditions, limited hygiene, and a transient workforce can “create an ideal environment for the transmission of infectious diseases.” [11] The intent of this analysis is to help understand that risk, in order to support risk-informed and data-driven decision making.

Fire personnel know all too well the occurrence and unpleasantness of “camp crud” [12], but the COVID-19 global pandemic may be dramatically different. Based on current understanding of the virus, it may be more infectious, last longer, and have higher infection fatality rates than prior infectious disease threats [13-17]. As of 04 May 2020, the estimated case fatality rate in the United States was 5.8%, according to the Johns Hopkins University and Medicine Coronavirus Resource Center [18]. The underlying infection fatality rate could be far lower1, however, due to an unknown but likely larger number of total infections due to factors such as limited availability of testing, testing errors, and asymptomatic cases [19-20]. Another unknown is the degree to which smoke exposure may exacerbate COVID-19 risks, although past research suggesting linkages between smoke and respiratory infections [21-23] make it an important consideration.

At present, the Wildland Fire Medical and Public Health Advisory Team has established interim standard operating procedures for screening wildland fire personnel [24], but is recommending against testing for a variety of reasons related to logistics and reliability [25]. Possible failures of screening and asymptomatic cases [20] suggest the prospect of personnel arriving to a large fire camp and spreading COVID-19. Under business as usual on a large, long-duration incident, the presence of infected individuals could lead to widespread infection.

Here we report preliminary findings from an epidemiological simulation model of COVID-19 based on parameters published in [13]. We tailor the model to the context of a wildfire incident, where the population at the fire camp changes over time. We explore how rates of infection and fatality vary with incident mobilization/demobilization dynamics, duration, and the number of assigned personnel using real resource assignment data from three historical fires. Further, we adjust the model to explore the benefits of two risk mitigations measures that incident management teams may adopt: screening/testing, and social distancing measures.

Methods

We simulate COVID-19 outbreaks on three 2017 fires chosen to represent different incident types: the Highline Fire, which burned for much of the summer but personnel peaked early in the effort, the Lolo Peak Fire, which spanned July through September and had a relatively symmetric mobilization and

1 The case fatality rate considers only confirmed cases, whereas the “true” underlying infection fatality rate includes both confirmed and unconfirmed cases; see https://www.npr.org/2020/04/24/844562935/why-the-true-fatality-rate-of-covid-19-is-hard-to-estimate

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demobilization phase, and the Tank Hollow Fire, which was shorter than the other two and had fewer personnel throughout the incident. Figure 1 shows the mobilization/demobilization dynamics for the personnel expected to be at camp for the three fires we selected, providing a sense of perspective on when in the season they occurred, how long they lasted, and how many personnel were on the fire. Data for these fires was obtained from the Resource Ordering and Status System (ROSS) (see [26-27] for other peer-reviewed studies of suppression resource allocation and movement using ROSS). Additional details on the modeling are provided in a Technical Appendix.

We feed these incident dynamics into the COVID-19 model to analyze different scenarios. Table 1 shows the variety of scenarios we analyzed regarding infection rates and entry rates of infected personnel. These scenarios range best to worst case along with two risk mitigation options: enhanced screening/testing (assuming testing may become more readily available and recommend for use further into the season), and aggressive social distancing at camp (e.g., no catering, increased use of spike camps, remote briefings). The best case assumes both mitigations are implemented jointly and effectively. We also explore variable infection fatality rates\(^2\), ranging from low (0.10%), medium (0.30%), high (1.00%), and extreme (2.00%). These fatality rates may differ from what has been observed for the general population due to responders’ increased smoke exposure and fatigue, among other factors.

![Total Personnel on 3 Incidents in 2017](image)

**Figure 1:** Total personnel assigned and expected to be at fire camp (e.g., non-aerial resources) for three large incidents over time; data from the Resource Ordering and Status System

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\(^2\) Note we adopt values for infection fatality rates that are lower than current observed case fatality rates

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Table 1: Scenarios and corresponding model parameters. The infection rate parameter is drawn from Wu et al. (2020) [13]; medium is the baseline observed rate of 2.38, low is half of the baseline (1.34), and high is twice the baseline (5.36). The percentage of individuals arriving at the fire infected is varied from low (0.1%) to medium (1%) to high (5%).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Infection rate (R0 parameter)</th>
<th>Percent of arriving individuals that are infected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best case</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Worst case</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Baseline</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Enhanced screening/testing</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Aggressive social distancing</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Results

Figure 2 shows the paths of infectious individuals and total infections under the baseline assumptions for each fire over time. Total infections are defined as individuals who became infected on the incident whether they remained on the incident or left. Maximum daily infections generally peak around the time of peak assigned personnel. Despite the Highline Fire having a greater number of assigned personnel at the peak, the Lolo Peak Fire had by far the greatest number of infected due to the longer duration with substantial personnel assigned and the total number of personnel that worked on the fire. The Lolo Peak also had the highest number of modeled fatalities (Figure 3), which in the extreme case could exceed 10 fire personnel. At low to medium infection fatality rates, we would expect near-zero fatalities on the Highline and Tank Hollow fires.

We explore the impact of enhanced screening/testing by varying the percentage of arriving individuals that are infected. Figure 4 compares the total number of infections on each fire under low, medium, and high percentages of infected arrivals at camp corresponding to different levels of screening/testing. The results indicate that screening and testing procedures are important for shorter duration fires where many people are entering and leaving the camp. However, on long-duration fires like Lolo Peak, many of the infections occur on the fire making the testing less important than aggressive social distancing (see below).

We explore the impact of aggressive social distancing by varying the transmission rate derived from R0 (the basic reproduction number, or the number of secondary cases resulting from a single case). Reducing contacts in the camp by dispersed camping or remote briefings will reduce transmission. Figure 5 compares the total number of infections on each fire under low, medium, and high transmission scenarios corresponding to different levels of social distancing. Social distancing is comparatively more effective than screening/testing, and can substantially reduce cases, especially on long duration fires like Lolo Peak.

Beyond the direct health impacts, infected persons are also unable to work, reducing the workforce available to contain the fire. The loss of personnel can be substantial: up to 10% of the workforce may

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be infectious on the single day with the maximum number of personnel on the fire (Figure 6) in the worst case scenario, though other scenarios show smaller effects (less than 5%). The most promising option appears to be implementing both aggressive screening/testing and social distancing measures on-site at the fire camp (Figure 7; best case). Certainly results are driven by the assumption that incoming infections and infection rates can be reduced, but nevertheless results do suggest aggressive mitigation can help sustain firefighting capacity over time.

**Conclusion**

The objective of this report is to provide enhanced situational awareness of potential COVID-19 and wildfire risks, and to inform development of mitigation strategies moving forward. Due to uncertainty we opted to explore a range of scenarios, and caution that results are illustrative, not definitive or predictive. Model results will be updated over time as additional information becomes available.

**Figure 2:** Infectious persons and total infected persons over the duration of each incident, under the baseline scenario. Note that the infectious status is temporary whereas the total number of infections is cumulative. Note that the vertical axis is log scaled.

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Figure 3: Cumulative fatality over time for the baseline scenario. Note that the vertical axis is not log scaled for this figure.

Figure 4: Total number of infected individuals over the duration of each incident under low (0.1%), medium (1%), and high (5%) entry rates of infected individuals. Note that the vertical axis is log scaled.
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**Figure 5:** Total number infected individuals over the duration of each incident under low (R0=1.34), medium (R0=2.68), and high (R0=5.36) infection rates. Note that the vertical axis is log scaled.

**Figure 6:** A comparison of the percentage of the workforce infected on the day with the largest number of personnel working across fires and scenarios.

**Figure 7:** A comparison of the total infected persons across fires and scenarios. Total infected for the best case scenario is approximately 8, 21, and 4 individuals for the Highline, Lolo Peak, and Tank Hollow fires, respectively.
Acknowledgments

We wish to thank Dr. James McCarthy and members of the Wildland Fire Medical and Public Health Advisory Team for their review and feedback on the epidemiological modeling. We also wish to thank Lynne Westphal, David Bengston, Jason Crabtree, and Robert Haight for their assistance with scenario analysis.

Disclaimer

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Author Bios

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Erin Belval is a Research Associate in the Department of Forest and Rangeland Stewardship at Colorado State University. Her research interests include data-driven analyses of fire operations, and she is currently a member of the Wildfire Risk Management Science Team at Rocky Mountain Research Station.

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Technical Appendix

We develop a compartmental epidemic simulation model based on [13] adapted to the context of a wildfire incident. Our model incorporates the movement of personnel to and from the incident which have important implications for disease transmission. The model divides the population into four health classes (Susceptible, Exposed, Infectious, and Removed). The outbreak evolves according to the following system of differential equations,

\[ \begin{align*}
\dot{S} &= -\frac{R_0 S(t) \cdot I(t)}{D_I} \cdot \frac{1}{N(t)} + (1 - D_{EIR})A(t) - \frac{S(t)}{N(t)}X(t) \\
\dot{E} &= \frac{R_0 S(t) \cdot I(t)}{D_I} \cdot \frac{1}{N(t)} - \frac{E(t)}{D_E} + D_{EIR}A(t) - \frac{E(t)}{N(t)}X(t) \\
\dot{I} &= \frac{E(t)}{D_E} - \frac{I(t)}{D_I} - \frac{I(t)}{N(t)}X(t) \\
\dot{R} &= \frac{I(t)}{D_I} \\
\dot{N} &= A(t) - X(t)
\end{align*} \]

where \( R_0 \) is the basic reproduction number indicating the number of secondary infections caused by an index case over the duration of the infectious period \( D_I \), \( N \) is the total population on the fire at time \( t \), \( A(t) \) is the number of new arrivals on the incident (all are assumed susceptible or exposed), \( X(t) \) is the number of individuals exiting the incident, \( D_E \) is the exposed, or incubation, period, and \( D_{EIR} \) is the entry infected rate.

The term \( \frac{R_0 S(t) \cdot I(t)}{D_I \cdot N(t)} \) represents the number of new infections at time \( t \). \( \frac{R_0}{D_I} \) is the rate of transmission conditional on contact between susceptible and infectious individuals in the population. New infections enter the exposed class during which time they are not infectious, but most certainly will become infectious. Individuals in the exposed class enter the infectious class at a rate of \( \frac{E(t)}{D_E} \).

Wildfire incidents are unique events to model because there are individuals arriving and leaving due to reassignment or demobilization. New personnel arrive on the incident according to \( A(t) \) and exit according to \( X(t) \). However, the exits are proportional to the population in each class at time \( t \). We estimate the number of personnel arriving and departing based on empirical data from ROSS.

We parameterize the model based on estimates from relevant literature (Table A1). Estimates of \( R_0 \) vary widely in the literature, but generally fall between 1.3 and 6 [28]. We use a baseline estimate of \( R_0 \) of 2.68 [13], and bound it by 1.34 (50% of 2.68) and 5.36 (200% of 2.68). While COVID-19 can affect individuals for several weeks [29], infected individuals with symptoms are likely to sequester themselves and be isolated from the susceptible population. Estimates from [29] suggest that the time from symptom onset to isolation is between 2 and 5 days. We assume that an infectious individual is mixing in

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the population for 3 days. Estimates of the incubation period, $D_E$, tend to lie between 4 and 6 days. We use 5 days in our models. We assume that 2 individuals enter the incident infected on the first day of the fire camp, which represents 1% of the peak personnel on the Tank Hollow Fire, the smallest of the three fires we profile.

Infection fatality rates vary widely in the literature because of demographic characteristics and variable testing. Early reports suggested that the case fatality rates may be as high as 6%; however, recent evidence suggests that it may be 2%-3%, and even lower in younger health populations [30]. Furthermore, emerging evidence suggests that case underreporting may imply about 10 true cases for every 1 case confirmed by testing. Adjusting the case fatality rate for underreporting leads to infection fatality rate of 0.3%. We also consider a low bound of 0.1%, which is in line with the 2009 H1N1 pandemic [31], and high estimates of 1% and 2%.

We consider various rates of infected individuals entering the population on the incident. While these infected entry rates depend on the behavior of individuals while off duty, they also may be influenced by screening procedures. We consider 0.1%, 1%, and 5% to capture the range of general population disease prevalence and potential effectiveness of screening procedures.

Table A1. Parameter values used in simulation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Extreme</th>
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<tbody>
<tr>
<td>$R_0$</td>
<td>1.34</td>
<td>2.68</td>
<td>5.36</td>
<td></td>
</tr>
<tr>
<td>$D_E$</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial I</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infection Fatality Rate</td>
<td>0.1%</td>
<td>0.3%</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Infected Entry Rate</td>
<td>0.1%</td>
<td>1%</td>
<td>5%</td>
<td></td>
</tr>
</tbody>
</table>
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