# Supporting Wildfire Response During a Pandemic in the United States: the COVID-19 Incident Risk Assessment Tool

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The onset of the global pandemic in 2020 significantly increased the complexity and uncertainty of wildfire incident response in the United States, and there was a clear role for decision support to inform and enhance coordination and communication efforts. Epidemiological modeling suggested the risk of COVID-19 outbreak at a traditional large fire camp could be substantial and supported the broadscale implementation of mitigations, and management of COVID-19 required expanding the response network to interface with entities such as local public health agencies, hospitals, and emergency operations centers. Despite the early issuance of medical and public health guidance to support wildfire management functions under a COVID-19 modified operating posture, an identified gap was a scale- and scope-appropriate tool to support incident-level assessment of COVID-19 risk. Here we review the development and application of a COVID-19 Incident Risk Assessment Tool intended to fill that gap. After prototyping with fire managers and risk practitioners, including early-season use on several incidents, we built an online dashboard that was used operationally throughout the 2020 fire season. We summarize usage statistics, provide some examples of real use on wildfire incidents, and report feedback from users. The tool helped to fill a critical information gap and was intended to support risk-informed decision-making regarding incident logistics, operations, and COVID-19 mitigations.

Keywords: COVID-19, decision support, dashboard, wildfire management, risk management

## INTRODUCTION

Response to wildfire incidents can be a complex and uncertain endeavor, with management challenges and prospective losses increasing as human development expands into burnable areas and climate change leads to increased fire activity (Thompson, 2013; Abatzoglou and Williams, 2016; Radeloff et al., 2018). Wildfire response organizations scale up as the size and complexity

of the incident increases, which necessitates networked coordination and communication across a variety of functions and with numerous local agencies, managers, and stakeholders (Nowell and Steelman, 2015; Nowell et al., 2018; Steelman and Nowell, 2019). Accordingly, there is a clear role for decision support to inform and enhance coordination and communication efforts (Greiner et al., 2020; Rapp et al., 2020).

The onset of the global pandemic in 2020 significantly increased the complexity and uncertainty of wildfire incident response in the United States. Even without an ongoing pandemic, large wildland fire response is logistically challenging as it can require hundreds to thousands of personnel to be assigned to a single incident. Traditionally, at each individual incident these personnel interact with each other in fire camps (the sites at which the personnel are provided with food, water, areas for sleeping, and sanitary services) and at incident command posts (the location where the primary logistics functions of the fire are administered.) These personnel move between fires over the course of the fire season; at each fire, individuals are exposed to a new group of personnel. Due to factors such as high-density living and working conditions, limited hygiene, smoke exposure, and a transient workforce, transmission of infectious disease was already a known risk associated with wildfire incident management activities in the United States[1]. Epidemiological modeling suggested the risk of COVID-19 outbreak at a traditional large fire camp setting could be substantial and supported the broadscale implementation of mitigations, including screening and social distancing measures such as expanded use of telecommunications rather than in-person briefings and dispersed rather than concentrated camping (Thompson et al., 2020). Further, management of COVID-19 required expanding the response network to interface with entities such as local public health agencies, hospitals, and emergency operations centers[2].

Despite early issuance of medical and public health guidance to support wildfire management functions under a COVID-19 modified operating posture[3], an identified gap was a scale- and scope-appropriate tool to support incident-level assessment of COVID-19 risk. The Wildland Fire Decision Support System (WFDSS) provides strategic functionality to estimate the relative risk for an incident but is focused on potential fire behavior and threats to assets and resources such as homes, critical infrastructure, and wildlife habitat (Calkin et al., 2011; Noonan-Wright et al., 2011; Zimmerman, 2012). Risk Assessment Worksheets used operationally do have a focus on risk to human health and safety but generally at the scale of the individual rather than the population[4].

Here we review the development and application of a COVID-19 Incident Risk Assessment Tool intended to fill that gap. After prototyping with fire managers and risk practitioners, including early-season use on several incidents, we built an online

dashboard that was used operationally throughout the 2020 fire season. The tool was designed to support the assessment of risks to firefighter health and workforce capacity at the level of the population of fire personnel assigned to the incident. More specifically, the tool was intended for use on large, long-duration incidents where hundreds to thousands of fire personnel can be mobilized, and where the likelihood of infectious disease transmission is generally higher. In addition to the risk of transmission, these fires tend to have more complex, multi-agency incident response organizations where enhanced communication and coordination can be essential.

The COVID-19 Incident Risk Assessment Tool was designed for the United States fire system, for use on individual incidents, with information and results intended for local users. Our ends-based objectives for the tool were that it could capture local and up-to-date knowledge of conditions, track changing conditions over time, promote situational awareness, help identify mitigations within the scope of control of the incident management organization, and, most importantly, facilitate communication, deliberation and information sharing throughout the interagency response network. As a means-based objective, and as suggested in early feedback, we wanted the tool to be simple to use and interpret by on-the-ground fire personnel who are typically under considerable time-pressures with high workloads.

In the subsequent sections, we first describe the design of the risk assessment tool, our communications plan to reach users, software implementation to build a user-friendly online dashboard, and our deployment and evaluation plan. We then summarize usage statistics, provide some examples of real use on wildfire incidents, and report feedback from users. Lastly, we identify possible improvements and opportunities for use in 2021.

## MATERIALS AND METHODS

## Risk Assessment Framework and Products

We structured the assessment as a hierarchical multi-criteria analysis. The scheme includes three risk factors (scored 3–9), each of which is rated based upon three-subfactors (scored 1–3), which are combined as a weighted sum. The risk factor ratings are then combined as a weighted sum to yield a numerical incident-level risk score and a corresponding qualitative risk rating. We selected this framework based in part on recommendations from the field to foster consistency and familiarity with existing assessment products in WFDSS.

Equation 1 displays the basic risk score calculation, assessing risk for the entire population of firefighters. For generality, we present an equation with the flexibility to accommodate different weighting schemes, although the current model uses equal weights of 1.0, such that the score can range from 9 to 27. Additionally, the model allows users to modify the final risk score to account for local risk factors not included in our model, such that the adjusted risk score can go up to 30. We conservatively defined the corresponding risk rating categories as: low (9–13),

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moderate (14–18), and high (19–30).

$$IRS = \sum_i \alpha_i \, FRS_i + \beta$$

$$FRS_i = \sum_j \gamma_{ij} \, SFRS_{ij}$$

Where:

| | |
|---|---|
| *IRS* | Incident Risk Score |
| *i* | Index for factor (*i*) |
| *FRS_i* | Risk Factor Risk Score for factor (*i*) |
| *ij* | Index for factors (*i*) and sub-factors (*j*) |
| $\gamma_{ij}$ | Importance weight of sub-factor (*ij*) for calculating the risk factor risk score (*i*) |
| $\alpha_i$ | Importance weight of risk factor (*i*) for calculating the incident risk score |
| *SFRS_ij* | Sub-Factor Risk Score (1–3) |
| $\beta$ | Additional user-specified incident-level risk factors |

**Table 1** provides specifics for the risk factors and sub-factors we identified. This language was embedded in the dashboard using textboxes that appeared when users hovered over the risk factor text, as well as being provided in PDF format on the dashboard to guide the interpretation and assessment of risk factors. We iterated over multiple versions of the scheme, and the final design choice reflects the balance of complexity and completeness versus ease and timeliness of use. Throughout, we solicited feedback from practitioners as well as medical and public health experts. We also incorporated insights from relevant epidemiological modeling of factors influencing COVID-19 outbreak risk at fire camp, including possibly correlated risk factors (e.g., number of personnel assigned and incident duration) that have differential impacts on COVID-19 risk (Thompson et al., 2020). For purposes of a high-level summary, and recognizing time demands on users, the tool did not request details on different groupings and interactions of firefighters assigned to the incident.

**TABLE 1 |** Guidance provided to users of the COVID-19 incident risk assessment tool for interpreting and assessing risk factors.

| Risk factor and sub-factor | Guidance |
|---|---|
| **ICP/Fire camp risk status** | Factors generally relating to the layout of the ICP/camp/base, number of personnel assigned, and duration of the fire, which in turn affect the nature and frequency of contacts, exposure potential, and disease dynamics. |
| Number of personnel | All else being equal, the greater the number of personnel assigned, the higher the likelihood of an infected individual getting missed by screening or the higher the likelihood of person-to-person contact and exposure. Thus, this variable is asking for the total personnel assigned to the fire who are not working remotely. |
| Camp dispersal | All else being equal, the less dispersed personnel are at camp, the higher the likelihood of person-to-person contact and exposure. This variable is rating if fire camp is highly dispersed with little interaction between firefighters outside of work on the fireline/ICP (highly dispersed) or if fire camp is functioning more traditionally, with high levels of interaction between personnel. |
| Camp duration | All else being equal, the longer the duration of the incident, the higher the likelihood of an infected individual entering camp and disease spreading throughout the camp population. This variable is counting days since the fire response began. |
| **Mitigation implementation status** | Factors generally relating to behaviors of personnel in camp(s) and when interacting with other individuals, which in turn affect the spread dynamics of the disease. See the CDC FAQs for Wildland Firefighters. |
| Screening frequency | All else being equal, screening lowers the opportunities for infected individuals to enter the fire. A screening tool has been provided by MPHAT. Screening must occur at least every time an individual arrives at the fire and daily thereafter to be classified as "always." |
| Social distance discipline | All else being equal, higher levels of social distancing lessen chances for the disease to spread. This term refers to adherence to "module of one" concept, keeping six feet distances between individuals, and minimizing all contacts outside of module as one, including minimizing contact with the general public. This does NOT refer to any camp dispersal measures as those are accounted for elsewhere. |
| Wearing masks | All else being equal, more frequent use of cloth masks by personnel lowers the overall camp risk. Cloth masks prevent the spread of disease as a form of source control and are thus protective for the camp as a whole. |
| **COVID risk status** | Factors generally relating to the status of COVID cases in the firefighting population and in the surrounding community that could affect likelihood of firefighter exposure or ability to treat ill firefighters. (Consider factors cited in the NMAC Interagency Checklist for Mobilization of Resources in a COVID-19 Environment, FS Guidance and Protocols to Implement the USDA Reopening Playbook). |
| Firefighter cases | All else being equal, as the number of firefighter cases goes up, so does the likelihood of additional exposures and infections. This variable is tracking both the number of individual cases and their location in the overall population—if infections are seen across multiple crews or "modules," then the possibility of within-camp transmission and outbreak risk is greater. |
| Local COVID cases | All else being equal, the more prevalent the disease is in the surrounding community, the higher the likelihood of exposure if there are contacts with community members. Consider also evaluating 14-day trajectories of documented cases per official state and regional gating criteria. |
| Local health care capacity | All else being equal, the lower the local capacity to treat firefighters should they become infected, the greater the concern over health outcomes. The important factor is the number of ICU beds relative to amount of fire personnel. |

*Language is reproduced exactly as it appeared on the dashboard and PDF. ICP, Incident Command Post. CDC, Centers for Disease Control. MPHAT, Medical and Public Health Advisory Team. NMAC, National Multi-Agency Coordinating Group. USDA, United States Department of Agriculture. FS, Forest Service. All websites accessed 23 November 2020. "Module of one" was an approach for crews and other groups to insulate as one unit to reduce exposure to the public and other crews.*

**Figure 1** displays the conceptual rose chart for how risk scores and ratings were visualized. The dashboard automatically creates figures for each factor and sub-factor and for the overall incident-level score. Each "petal" corresponds to an individual risk sub-factor, the size and color of which vary depending on the assigned score. **Figure 2** displays how each factor and sub-factor are rated on the dashboard itself. The greater the size of a petal, the greater its contribution to overall risk. **Table 2** displays the risk assessment worksheet that forms the basis for how the chart is created. This worksheet was available for users as information and as a tool to download and fill out by hand. In practice, the target user base is a comparatively small fraction of the fire management community; one or a few persons per Incident Management Team would be sufficient to gauge risk and initiate meaningful conversation.
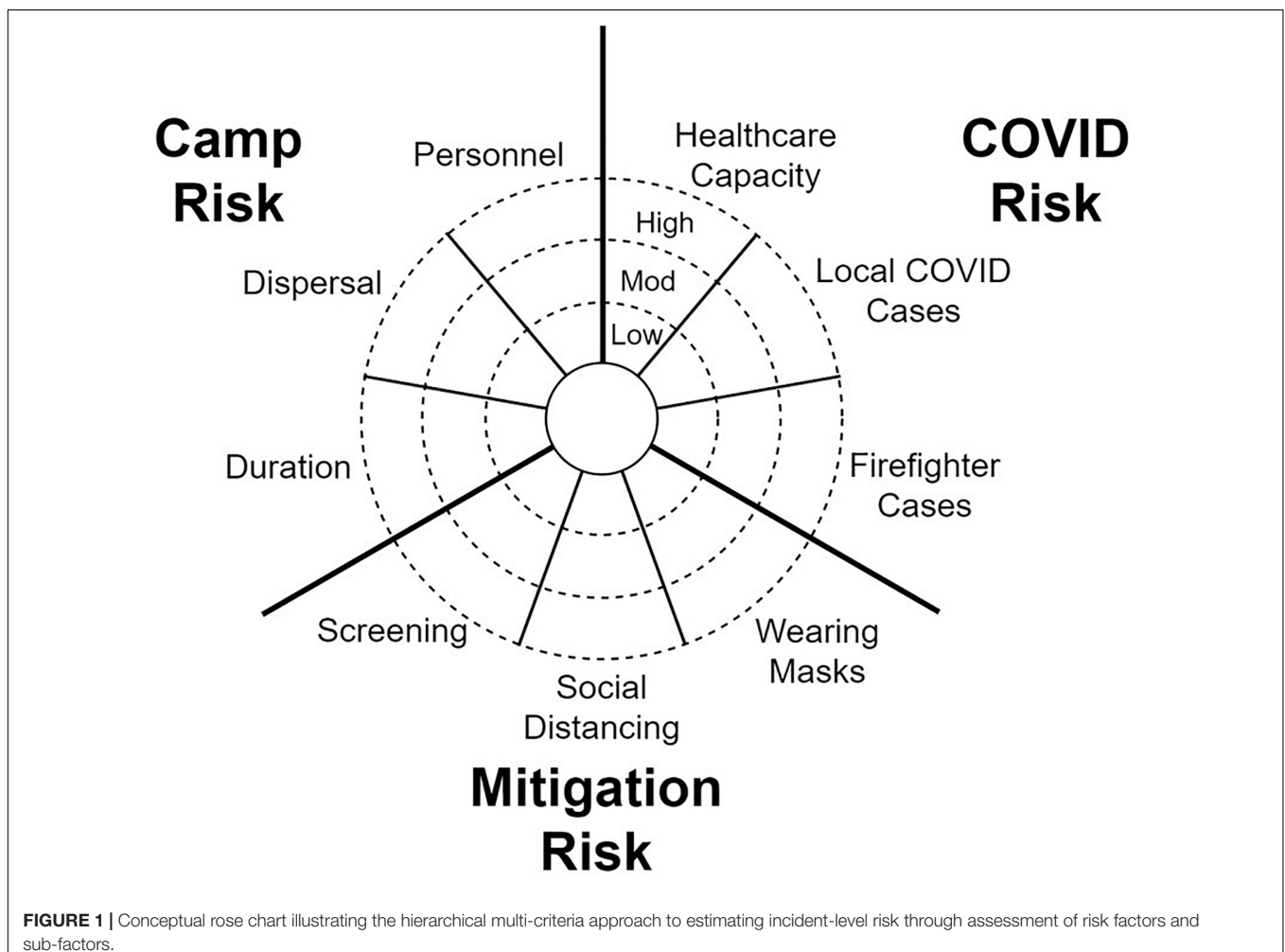
## Prototyping, Communication, and Outreach

In late June and early July 2020, an initial version of the risk assessment tool was used on multiple wildfire incidents in the southwestern United States. At the time, we had only developed the framework and shared an image mirroring the depiction of the tool with the relative risk assessment from WFDSS. Assessment results were hand-drawn and shared with accompanying text narrative. Based on positive feedback from regional risk management specialists familiar with the tool's operational use, we proceeded with updating the graphical model and developing the software to streamline and expand the use of the online risk assessment tool.

In addition to working with subject matter experts and relying on their respective networks, we used multiple channels to share information about the COVID-19 Incident Risk Assessment Tool. Early on, we briefed senior leadership of the USDA Forest Service, who offered their support for continued development and use. We coordinated closely with agency personnel from Fire and Aviation Management, Office of Communications, and the Rocky Mountain Research Station. With their assistance, we developed an informational webpage about the project as well as an online tutorial hosted on the dashboard[5].

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[5]https://www.fs.usda.gov/rmrs/tools/covid-19-fire-incident-specific-risk-assessment-tool



**FIGURE 1 |** Conceptual rose chart illustrating the hierarchical multi-criteria approach to estimating incident-level risk through assessment of risk factors and sub-factors.
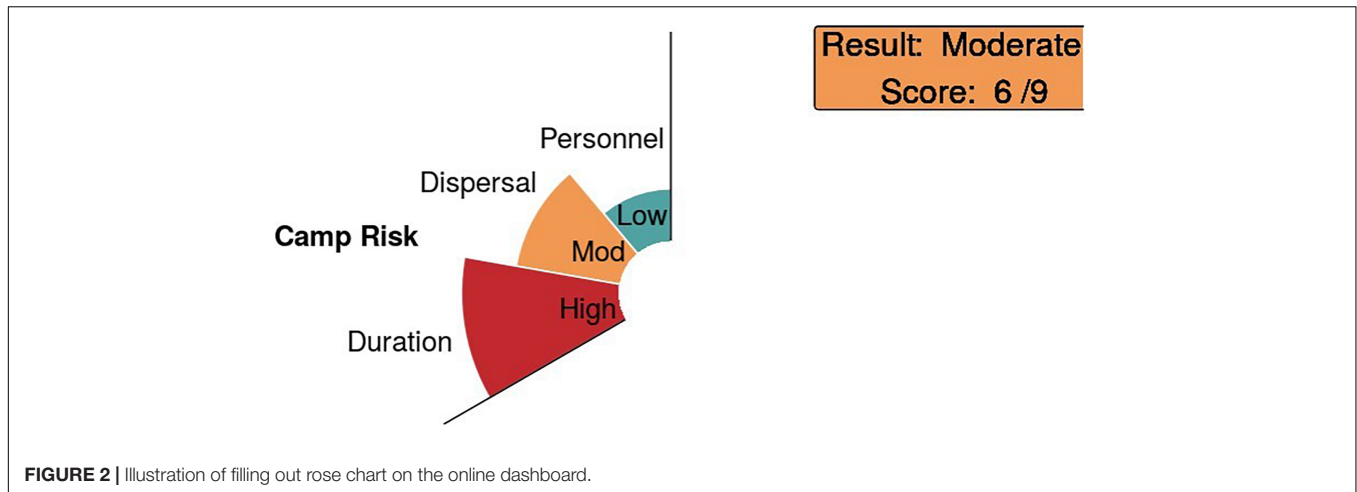
**FIGURE 2 |** Illustration of filling out rose chart on the online dashboard.

**TABLE 2 |** Risk Assessment Worksheet that lays out the risk scoring and rating system all factors and sub-factors.

| Risk factors | Low risk | Moderate risk | High risk | Score | Rating |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | | |
| **ICP/Fire camp risk status** | | | | | |
| Personnel | Low (50–200) | Mod (200–500) | High ( > 500) | | |
| Camp dispersal | High dispersal | Moderate dispersal | Low dispersal | | |
| Camp duration | Short ( < 5 days) | Medium (5–20 days) | Long ( > 20 days) | | |
| **ICP/Fire camp risk factor total** | | | | | |
| **Mitigation implementation risk status** | | | | | |
| Screening frequency | Always | Sometimes | Never | | |
| Social distancing Discipline | High compliance | Moderate compliance | Low compliance | | |
| Cloth masks | Always | Sometimes | Never | | |
| **Mitigation implementation risk factor total** | | | | | |
| **COVID risk status** | | | | | |
| Firefighter cases | Low ( < = 2) | Mod ( > 2, isolated) | High ( > 2, many) | | |
| Local cases | Low amount | Mod amount | High amount | | |
| Healthcare capacity | High capacity | Mod capacity | Low capacity | | |
| **Surrounding area and community COVID risk factor total** | | | | | |
| **Additional risk factors (Optional)** | | | | | |
| Smoke, etc. | | | | | |
| **Final relative risk assessment** | | | | | |
| Incident risk total | | | | | |

A primary channel we leveraged was virtual meetings hosted by Incident Management Remote Response (IMRR), a collaborative interagency effort to support rapid sharing of information and lessons learned across the fire response community. Through IMRR, we presented to groups of Incident Commanders, Agency Administrators, and Safety Officers, with hundreds of attendees in some cases. In these sessions, we provided contact information and were able to follow up directly with interested personnel, in some cases supporting the use of the tool in real-time. Lastly, we collaborated with the Joint Fire Science Program who distributed information about our tool through the Fire Science Exchange Network.

## Software Implementation

We built the COVID-19 Incident Risk Assessment tool using the R Statistical Computing Language (R Core Team, 2019). **Table 3** lists the packages we utilized as well as the reason each package was necessary. The dashboard was developed as a Shiny app and provided to incident managers using the shiny.io server. The dashboard features a landing page that provides an overview of the decision support tool as well as links to a video introduction and a PDF allowing for offline incident risk assessment. From the landing page, users can navigate to the incident risk assessment tool. Once at the incident risk assessment tool, users are provided with an explanation of each risk factor and dropdown menus to input values for each sub-factor. The dropdown menu for each sub-factor provided a brief description of each sub-factor level. Initial values for all sub-factors were set to be empty, with empty spaces where the risk factor graphs and scores appear. The app accepts user inputs and updates dynamically. Once the user populates values for all three of the sub-factors associated with a risk factor, the score for that risk factor is calculated, and the

**TABLE 3 |** R packages used in the development of the dashboard.

| Package name | Version | Purpose | Available |
| --- | --- | --- | --- |
| ggplot2 | 3.3.2 | graphing | https://cran.r-project.org/web/packages/ggplot2/index.html |
| Shiny | 1.5.0 | web application framework | https://cran.r-project.org/web/packages/shiny/index.html |
| shinyBS | 0.61 | tooltip functionality | https://cran.r-project.org/web/packages/shinyBS/index.html |
| shinydashboard | 0.7.1 | dashboard layout tools | https://cran.r-project.org/web/packages/shinydashboard/index.html |
| shinyWidgets | 0.5.4 | input aesthetics | https://cran.r-project.org/web/packages/shinyWidgets/index.html |
| Dplyr | 1.0.2 | data wrangling/manipulation | https://cran.r-project.org/web/packages/dplyr/index.html |
| Stringr | 1.4.0 | string manipulation | https://cran.r-project.org/web/packages/stringr/index.html |
| Lubridate | 1.7.9.2 | date manipulation | https://cran.r-project.org/web/packages/lubridate/index.html |
| Purrr | 0.34 | working with vectors in functions | https://cran.r-project.org/web/packages/purrr/index.html |

graph and factor score appears in an image for the user to see. Once all nine risk sub-factors are scored by the user, the final incident risk score is calculated, and this, in addition to the graph combining all nine sub-factors, is presented to the user. Graphs are created using the package ggplot2. The graphs are represented as bar charts in polar coordinates. We graph the values of the sub-factors directly. The dashboard presents each subsection of the graph that is associated with each risk factor separately, with the final graph showing all risk factors together as the final output. The code repository for the dashboard is available online through GitHub (Dilliott, 2021).

In addition to the dropdown menus for each sub-factor, there are textboxes for users to provide the rationale for their ranking of each sub-factor. These rationales are not used in any of the risk score calculations. Rather, those fields are provided so that users may document and share information they used to come to their decisions. We provided the ability for users to download their full report as a PDF file; the rationales users provided for each risk sub-factor are printed on the PDF as well as each sub-factor score, the final risk score, and the complete graph. This PDF functionality was designed to allow users to easily share their results and rationales with others.

Once users completed their incident risk assessment, they were given the option to submit the full risk assessment to our modeling team along with information identifying themselves, their role in the incident management team, the fire on which they used the assessment, and any feedback they wanted to provide. These submissions were logged in an online spreadsheet and were used to identify potential improvements to the decision support tool and to provide context for how the tool was used on wildland fire incidents. Making submission of incident data voluntary was a design choice to encourage use by minimizing privacy or data tracking concerns.

## Deployment and Evaluation

After prototyping and outreach efforts were complete, the COVID-19 Incident Risk Assessment Tool was released for operational use by appropriate individuals in the fire management community at their discretion. Field users on fire assignments generated the input data, interpreted the results, and communicated them within their incident response organizations and with partners. From this point forward, we made no further adjustments to the model but did aid with use and interpretation as requests arose.
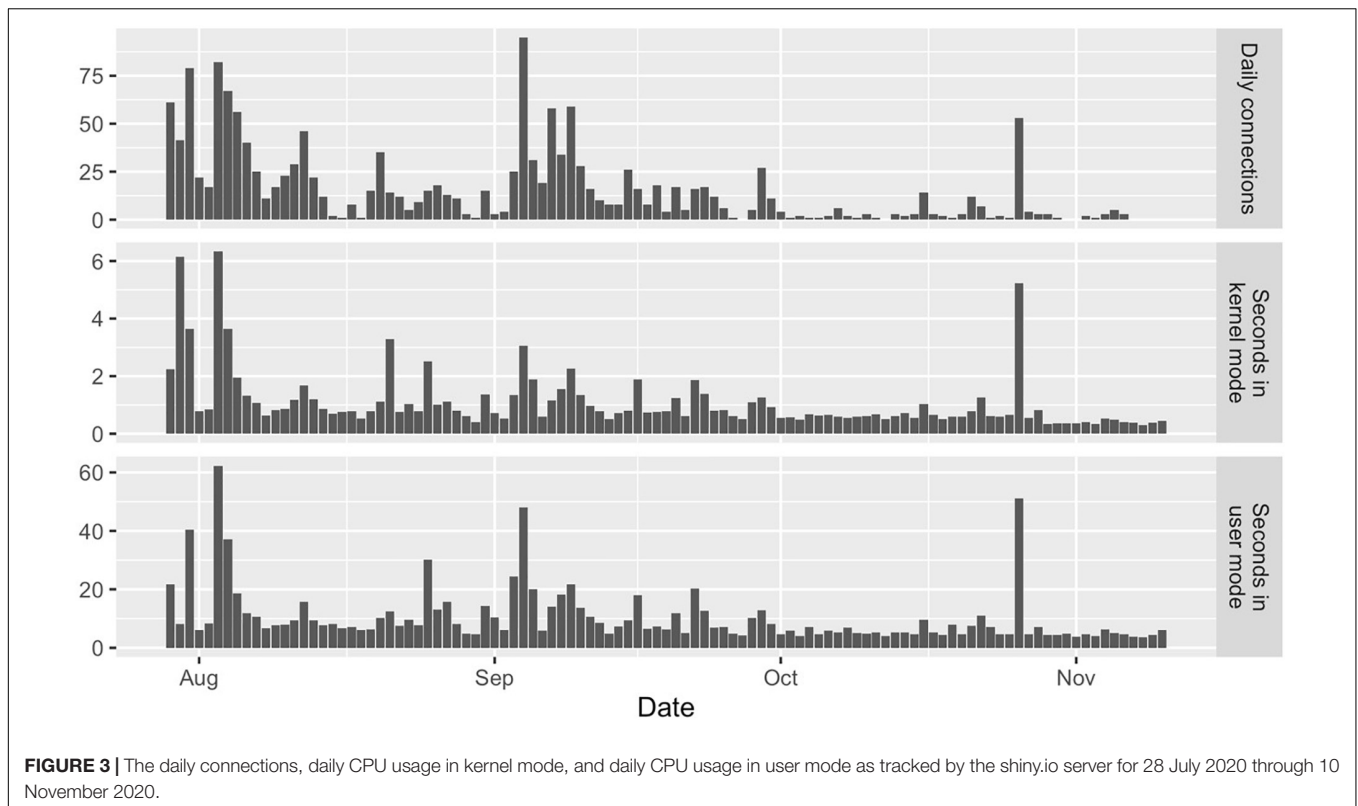
The tool was developed under compressed time frames to support the immediate needs of the fire management community. Because the tool was released during an extreme fire season coincident with a pandemic, respondents from whom we solicited feedback were also operating under considerable time pressures and stresses. The prospect of limited documentation on use was foreseeable (including the possibility of offline use with the PDF version in areas with limited connectivity), as was the prospect of not knowing the total number of wildfire incidents at which the tool was used. These were acceptable tradeoffs, and we prioritized supporting COVID-19 assessment, mitigation, and communication efforts over comprehensively tracking and evaluating use. Nevertheless, we developed a three-tiered approach to evaluation of the tool: (1) tracking online usage statistics; (2) examining actual use cases; and (3) examining user feedback.

## RESULTS

### Usage Statistics

We initially tracked dashboard usage using the built-in functionality provided by the shiny.io server. The usage statistics are tracked by the minute and include the number of active connections, Central Processing Unit (CPU) kernel usage in nanoseconds, and CPU user usage in nanoseconds. These usage statistics are shown over time in **Figure 3**, starting on 28 July 2020. The number of daily connections can be used as an estimate of the number of site visits the dashboard received. Because a single user may connect to the dashboard more than once per day, that metric can be higher than the number of daily unique site users.

The amount of CPU time used in kernel mode is associated with computing tasks such as application initiation, while the amount of CPU time used in user mode is associated with tasks such as application usage. Thus, for our dashboard, higher ratios of user mode to kernel mode CPU usage are likely to indicate users that are actually interacting with the dashboard as opposed to users who simply visit the site and do not interact with the application. These statistics from the shiny.io server show spikes in connections during key publication events such as the initial distribution the week of 28 July 2020, an email highlighting the application that was sent out on 4 September 2020, and a presentation that mentioned our team's work on 20 October

**FIGURE 3 |** The daily connections, daily CPU usage in kernel mode, and daily CPU usage in user mode as tracked by the shiny.io server for 28 July 2020 through 10 November 2020.

2020. However, we also observe ongoing routine usage of the app between publication events.

To improve tracking of dashboard usage, on 10 September 2020, we enabled tracking by Google Analytics. We used the standard Google Analytics settings. The use of Google Analytics allowed us to track additional data on users, including location, and if the visitor was new or returning. **Figure 4** shows the geographic distribution of new and returning users from 10 September 2020 through 10 November 2020. The dashboard saw usage across all regions of the United States, both for new visitors and returning visitors. According to the tracking done by Google Analytics, most users of the dashboard visited only once (150 users between 10 September and 10 November 2020). However, there were 20 users who visited the dashboard twice and 15 users who visited the dashboard between three and eight times. Google Analytics may underestimate returning visitors, as users who use more than one device can be considered a new user for each device. These dashboard user statistics may slightly underestimate the usage of this decision support tool, as we did provide decision-makers with a fillable PDF that could be used offline. In summary, usage statistics indicate sustained use of the tool by a variety of users in a variety of locations throughout the fire season.
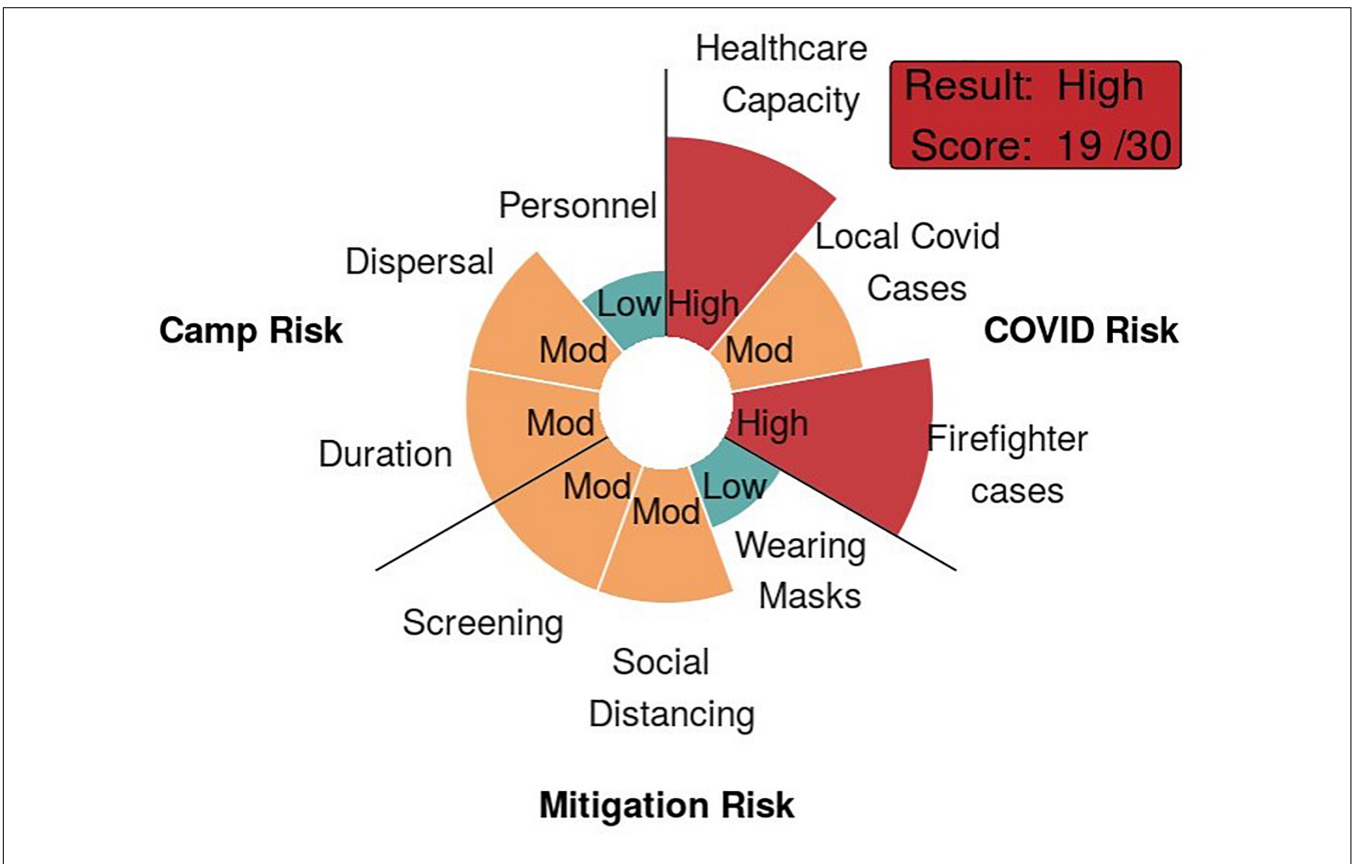
## Use Cases

For illustrative purposes, here we present risk assessment results and user-specified rationales for a real incident. We anonymize any data that could identify personnel or the incident, consistent with our statement to users that the tool was for informational purposes only and would not be used for any official record keeping or documentation. **Figure 5** displays the finalized rose chart with the overall risk score (19) and risk rating (high) from the real incident example. **Table 4** provides the accompanying rationales for all sub-factors. In this specific instance, Camp Risk Status and Mitigation Risk Status both rated as moderate, whereas COVID Risk Status rated as high, due to multiple cases among fire personnel and concerns over limited local healthcare capacity. As a point of comparison, **Figure 6** displays the finalized rose chart for an incident rated as moderate risk, and with very different breakdown of risk factors. In that case, the highest risk factor was ICP Risk Status, with an expectation of many personnel and a long-duration incident, but with the ability to widely disperse fire personnel at a large fire camp.

It is worth reiterating that the primary intention of the tool was facilitating communication and coordination rather than predicting where COVID-19 spread might occur. With that said, comparison of assessment results against observed case counts could help validate the internal logic of the assessment framework. Unfortunately, data on firefighter case counts is of poor quality and federal wildfire management agencies in the United States did not publish official counts for COVID-19 cases occurring on wildfire incidents. To provide one example of validation, with an admittedly limited scope of inference, we are aware of one incident where the final score was 21/30 with a rating of high risk where widespread testing, contact tracing, and quarantining/isolating were initiated, and ultimately where multiple cases were confirmed (again, the incident details are anonymized).
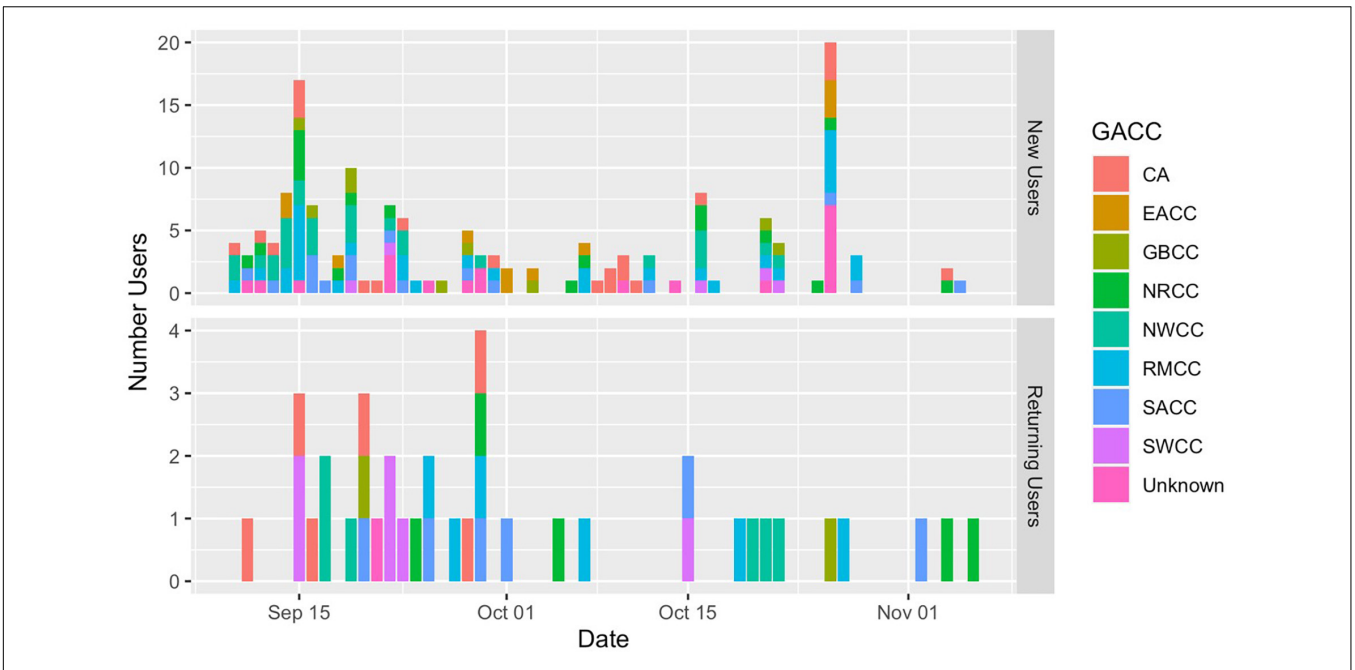
FIGURE 4 | The number of dashboard users in the United States classified by geographic area coordinating center (GACC) and user status (new or returning) as tracked by Google Analytics for 10 September 2020 through 10 November 2020. CA, California (a merging of the Northern and Southern California Coordination Centers); EACC, Eastern Area Coordination Center; GBCC, Great Basin Coordination Center; NRCC, Northern Rockies Coordination Center; NWCC, Northwest Coordination Center; RMCC, Rocky Mountain Coordination Center; SACC, Southern Area Coordination Center; SWCC, Southwest Coordination Center.



FIGURE 5 | Rose chart results from actual use case rating out as high risk (risk score of 19).

**TABLE 4 |** User-specified rationales from actual use case rating out as high risk (risk score of 19).

| Risk factor and sub-factor | Risk Rating | Rationale |
| --- | --- | --- |
| **ICP/Fire camp risk status** | | |
| Personnel | Low (+1) | 200 OR LESS INDIVIDUALS; IMT PROJECTING A DOWNSIZE IN COMING DAYS |
| Camp dispersal | Low (+1) | CREWS OPERATING AS A MODULE OF ONE; PLENTY OF ROOM FOR ICP TO SPREAD OUT |
| Camp duration | Moderate (+2) | MANY CREWS NEARING THE END OF THEIR TOUR; ONLY EXTENSIONS HAVE BEEN THOSE INDIVIDUALS WHO ARE QUARANTINED/ISOLATED |
| **Mitigation implementation risk status** | | |
| Screening frequency | Moderate (+2) | SCREENING PROCEDURES ARE USED AS A CREW MOBILIZES AND DAILY; SOME CONCERN THAT THE SCREENING PROCESS IS NOT EFFECTIVE ENOUGH BECAUSE IT RELIES ON THE HONOR SYSTEM |
| Social distancing discipline | Moderate (+2) | SOCIAL DISTANCING IS USED ON A DAILY BASIS; SOME CONCERN WITH SOCIAL DISTANCING DURING INDOOR BRIEFINGS- MITIGATIONS HAVE BEEN PROPOSED; CONCERN WITH SOCIAL DISTANCING WHEN THE IMT IMPLEMENTS ARENA SLEEPING ARRANGEMENTS |
| Cloth masks | Low (+1) | OBSERVED 80–90% FACE COVERING COMPLIANCE IN SEVERAL LOCATIONS |
| **COVID risk status** | | |
| Firefighter cases | High (+3) | SEVERAL CASES IN THE LAST WEEK RESULTSING BOTH IN QUARANTINE AND ISOLATION; COORDINATION WITH LOCAL PUBLIC HEALTH HAS HELPED CONTROL THE SITUATION; NO NEW CASES/EXPOSURES IN THE PAST 3 DAYS |
| Local cases | Moderate (+2) | 12 NEW CASES IN [xx] COUNTY; RISK LEVEL HAS INCREASED FROM LOW TO MODERATE |
| Healthcare capacity | High (+3) | MANY IF NOT ALL CASES WOULD BE TRANSFERRED TO HEALTHCARE SYSTEMS OUTSIDE OF THE LOCAL COMMUNITY; LITTLE TO NO CAPACITY FOR TREATING LOCAL COVID CASES |
| **Additional risk factors (Optional)** | | |
| | Low (+1) | COLD WEATHER IS CHANGING SLEEPING ARRANGEMENTS TO ALLOW FOR INDOOR SLEEPING IN MODULES; PLAN IS IN PLACE AND LOGISITICS TEAM WILL REMAIN FLEXIBLE TO NEW SITUATIONS AS THEY ARISE; MESSAGING SHOULD CONTINUE TO FOCUS ON INDIVIDUAL SYMPTOM REPORTING AND AVOIDANCE OF PUBLIC SPACES TO INCLUDE BARS AND EATERIES AS MASK DISCIPLINE IS NOT CONSISTENT IN [] COUNTY. |

## User Feedback

A variety of personnel used the tool, including Agency Administrators, Safety Officers, Medical Unit Leaders, and COVID Advisors. **Table 5** presents a select set of statements from real users and consumers of the COVID-19 Incident Risk Assessment Tool. Safety Officers appear to have been the primary user role, unsurprising given their responsibility to monitor all matters relating to the health and safety of response personnel. Feedback was generally positive, and notably emphasized how the tool enhanced communication and coordination, especially across organizations like county commissioners and local public health agencies. However, at least one user noted the subjectivity of some of the risk factors and questioned whether they "got it right." This points to a continued need to emphasize that the tool is not intended to be precise or predictive but rather to stimulate deliberation and communication. We will return to these points in the next section.

## DISCUSSION

The COVID-19 Incident Risk Assessment Tool was a rapidly developed product, built for an urgent need under considerable time pressure and uncertainty. The tool joins a body of online tools to support risk informed COVID-19 decision-making (e.g., Chande et al., 2020) and that emphasize human health and safety risks to firefighters (e.g., Viegas et al., 2009; Lahaye et al., 2018; Sol et al., 2018; Campbell et al., 2019; Dunn et al., 2019;

Jolly et al., 2019; West et al., 2020). Early use and feedback from the field improved the product and facilitated iterative prototyping, including multiple combinations of risk factors and different approaches to visualization.

The tool was not intended to be predictive, but rather its primary contributions were in supporting the identification of risk factors and available mitigations, and in serving as a communication tool. Because of time pressures, the environment in which managers were operating, the rapid deployment of the tool during an ongoing fire season, and the choice to limit the collection of information, measures regarding the use of the tool are limited. We acknowledge limited feedback gathered from the field. However, use on even a modest number of incidents by the target user community can have an outsized impact as managers of the larger, longer duration, more complex incidents can be managing hundreds to thousands of individuals. Further, from the measures we do have as well as feedback from the field, it seems apparent that the tool helped to fill a critical information gap and supported risk-informed decision-making regarding incident logistics, operations, and COVID-19 mitigations (**Table 5**). Usage statistics indicate operational use across multiple incidents over time and spanning multiple geographic areas (**Figures 3**, **4**). Although not the only measure of success, the reception has been positive from agency leadership down to the operational users. We acknowledge a degree of subjectivity but would emphasize the intent to support risk-informed assessment and communication based on local conditions and expertise.
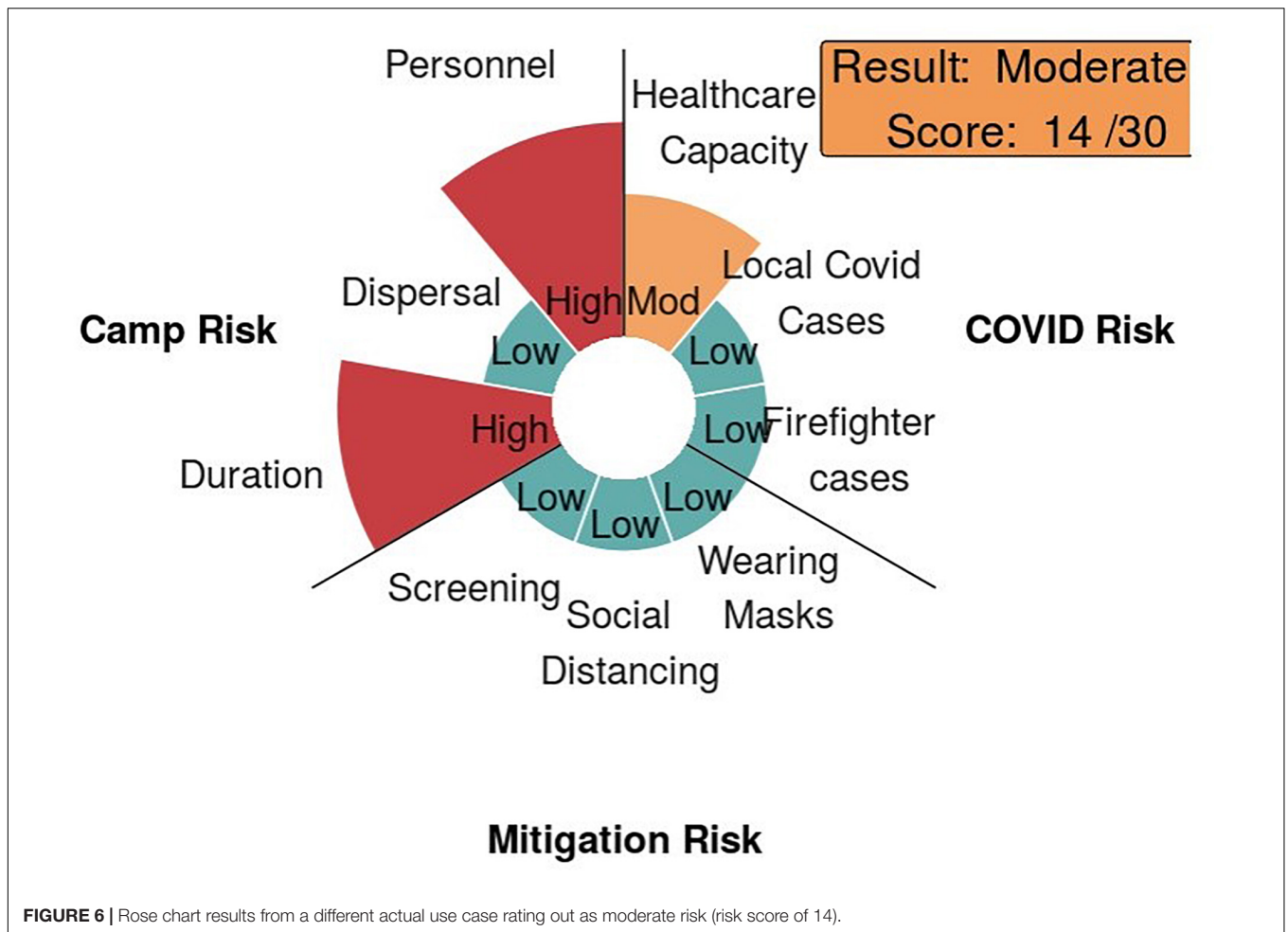
**FIGURE 6 |** Rose chart results from a different actual use case rating out as moderate risk (risk score of 14).

**TABLE 5 |** Feedback from users and consumers of COVID-19 Risk Assessment Tool, with user role identified. BOCC, board of county commissioners. AA, Agency Administrator, IMT, Incident Management Team.

| Feedback | Role |
|---|---|
| "Very helpful…Really helpful as a visual to interact with local Public Health and BOCCs" | Incident Commander |
| "…it was extremely helpful to our AA's in securing motel rooms for all resources (Engines and crews) and not just the IMT." | Safety Officer |
| "This should be used by all incidents and attached to the request by the ordering unit. It is easier to approve mobilization with this information, than it is trying to glean logistical support in place for off-unit resources in the event of exposure or infection." | Wildfire Operations Supervisor |
| "Very useful tool to communicate risk. The subjective elements could use a little more definition as I am left wondering if I "did it right." Overall I think this will serve as a useful reference for discussion with (state agency.)" | Safety Officer |
| "I found this to be a very valuable tool for evaluating our COVID risk on our fire" | Safety Officer |

Although not discussed here, in addition to the risk assessment functionality, our dashboard also allowed users to examine various incident scenarios using the epidemiological modeling presented in Thompson et al. (2020). Looking ahead, we plan to update this epidemiological modeling to account for individual interactions and variability in proportions of firefighters with a degree of immunity. We also intend to keep the risk assessment dashboard online, and pending analysis of empirical case and vaccine rates in the firefighting community may update the risk assessment framework. Ideally, the relationships between incident management teams and public health officials, and others, established during the 2020 wildfire season can be reinforced to support information exchange (Steelman et al., 2014), and the COVID-19 Risk Assessment Tool can facilitate those efforts.

## DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://github.com/jakedilliott/ciraDash.

## AUTHOR CONTRIBUTIONS

MT and EB led development and prototyping of the tool. JD, EB, and JB led development of the online dashboard. MT led communication and outreach to the fire management community. All authors contributed to the manuscript.

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