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World Safety Organization

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Cover Photo

Some facts on wildfires

- According to federal data published by the National Park Service, people are responsible for 85 to 90 percent of all wildfires in the United States every year.
- According to the National Centers for Environmental Information's Annual 2021 Wildfires Report, fire consumed nearly 7 million acres of wild area during that year.
- According to the National Interagency Fire Center, California has the most wildfires and acres burned in the United States.
- In 1825, one of the greatest fires in recent history raged over Maine and New Brunswick, Canada, destroying 3 million acres of forest.
- Over 100,000 lightning strikes hit the planet every day; 10% to 20% of these lightning strikes result in a fire.
- Every year, an estimated 1.2 million acres of US woods burn.

Retrieved from:
https://www.iii.org/fact-statistic/facts-statistics-wildfires
https://www.dosomething.org/us/facts/11-facts-about-wildfires

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All articles shall be written in concise English and typed with a minimum font size of 12 point. Articles should have an abstract of not more than 300 words. Articles shall be submitted as Times New Roman print and presented in the form the writer wants published. On a separate page, the author should supply the author's name, contact details, professional qualifications, current employment position, a brief bio, and a photo of the author. This should be submitted with the article.

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The application of portable air cleaners in spaces occupied by vulnerable people during wildfire events

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KEYWORDS

Portable Air Cleaner
PurpleAir
Wildfire Event

ABSTRACT

In this study, PM2.5 concentrations were collected and documented during wildfire smoke impacted days using PurpleAir PA-II sensors at three different locations in a community located in the northwestern United States. Each location was comprised of three co-located sensors with one sensor positioned outdoors, one sensor indoors, and one sensor indoors with an air cleaner in the room. The relationship between both indoor and outdoor PM2.5 concentrations provided evidence on the effectiveness of sheltering indoors from wildfire smoke events with and without an air purification system.

1. INTRODUCTION

Increased wildfire frequency and severity throughout the western United States have led to increased human exposure to wildfire-induced fine particulate matter ≤ 2.5µm (PM2.5) (Lydersen, 2017). The mixture of pollutants in wildfire smoke can depend on the geographic location of the burn area (Liang, 2021). Wildfire smoke plumes can travel great distances and settle into surrounding communities (Preisler, 2015).

The Environmental Protection Agency (EPA) has established both a 24-hour and an annual standard for PM2.5 as a component of the National Ambient Air Quality Standards (NAAQS) under the Clean Air Act. These guidelines are designed to protect the general population from increased risk of negative health effects from long/short-term exposure (U.S. EPA, 2020). Most recently, the 24-hour and annual standards have been reviewed by the EPA at 35 $\mu g/m^3$ and 12 $\mu g/m^3$ respectively (U.S. EPA, 2020).

Air monitoring for wildfire smoke is formally conducted through each state, using criteria set forth by the Office of Air Quality Planning and Standards (OAQPS) (U.S. EPA, 2016). Air quality stations are strategically located to represent a large geographic area. Size-selective sampling for PM2.5 is conducted through various EPA reference and equivalent methods in accordance with 40 CFR Part 53 (U.S. EPA, 2016). Low-cost sensors (< $1000) use advancing technology to understand and

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communicate air quality on a consumer level, when compared to reference instruments (EPA, 2021). Consumer monitoring products can be used on an individual level to measure particulate matter concentrations in a variety of locations (EPA, 2021). These consumer devices are widely used across rural areas where formal monitoring does not occur (EPA, 2021).

The health effects of wildfire-induced PM2.5 exposure include coughing, trouble breathing, scratchy throat, headache, and much more (U.S. EPA, 2019). The most vulnerable populations in terms of harmful effects from PM2.5 exposure are the youth, older adults, and the transitory population (U.S. EPA, 2019). As PM2.5 concentrations rise, the common guidance from healthcare officials is to take shelter by staying indoors, keeping windows closed, and using a portable air cleaner (PAC) (Xing, 2016).

Portable Air Cleaners (PACs) aid in the filtration and removal of particulate matter inside buildings. Each PAC is rated for a given room volume, where it can effectively eliminate contaminants with the appropriate filter. The use of HEPA filters can provide the added benefit of reducing airborne particles like dust, mold, viruses, and bacteria. PACs have been demonstrated to significantly reduce indoor PM2.5 concentrations associated with wildfire smoke (Stauffer, 2020).

2. OBJECTIVE

The primary objective of this study was to evaluate the effectiveness of staying indoors during a wildfire event and staying indoors with a PAC operating during wildfire events in settings occupied by traditionally vulnerable groups. Indoor and outdoor air quality measurements were taken at three different sites in a community located in the northwestern United States. Previous research has shown the effectiveness of commercial and "do it yourself" (DIY) PACs at controlling PM2.5 concentrations for office workers exposed to wildfire smoke in this same community (Stauffer, 2020). Each site in this study was selected based on occupant designation (youth, older adult, transient), room size, and proximity to a DEQ county air monitoring station. Ideally, this study was intended to evaluate the effectiveness of each sheltering method, depending on wildfire-induced PM2.5 concentrations. Furthermore, a secondary objective of this study was to compare PM2.5 exposure at each location based on the time of day, and the time spent in each PM2.5 concentration level.

3. BACKGROUND

3.1 Background of PM2.5

The increase in frequency and severity of wildfires throughout the western United States has resulted in an increased average amount of wildfire-induced smoke exposure (Lydersen, 2017). Components of wildfire smoke include gaseous pollutants, water vapor, and particulate matter. PM represents the main component that poses a public health threat. PM2.5, commonly referred to as fine particulate matter, refers to particulates with an aerodynamic diameter $\leq 2.5\mu m$. Particles of this size will tend to deposit throughout the respiratory tract. A smaller fraction can deposit into the alveolar region of the lungs, which may cause respiratory illness (Li, 2019). Common health effects associated with wildfire-induced PM2.5 can range from coughing and eye irritation to much more severe such as cardiovascular effects. The resultant smoke PM2.5 concentrations are measured by ambient air monitors and samplers located worldwide. The U.S. EPA must regularly update and revise national air quality standards for PM2.5, under the Clean Air Act.

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3.2 Wildfire Smoke Infiltration

The infiltration of wildfire smoke from outside to inside is a major factor that leads to human exposure to PM2.5 indoors during wildfire events (Pantelic, 2019). The infiltration of wildfire smoke has been studied in residential homes, as well as industrial buildings. Infiltration into larger industrial buildings largely depends on the type of ventilation system being used, and the building construction. Pantelic et al. (2019) compared two industrial buildings, one used a mechanical ventilation system with two-stage particle filtration, and one relied on natural ventilation during wildfire events. The particle filtration consisted of a first stage minimum efficiency reporting value (MERV) 8 pleated filter, and the final stage MERV 13 filter (Pantelic, 2019). The building with two-stage particle filtration had a mean indoor PM2.5 concentration of 21 $\mu g/m^3$, and an indoor/outdoor ratio of 0.27 (Pantelic, 2019). The building with natural ventilation had a mean indoor PM2.5 concentration of 36 $\mu g/m^3$, and an indoor/outdoor ratio of 0.67 (Pantelic, 2019). Wildfire smoke infiltration into residential homes is largely due to natural ventilation, and the opening of windows and doors (Barn, 2007). Barn et al. (2007) found that the infiltration factor for 17 homes in British Columbia, Canada during the wildfire season was 0.61 (Nguyen, 2021). Newly constructed homes built with central air conditioning systems were more effective at keeping wildfire smoke out, when compared to older homes in areas of lower socio-economic status (Liang, 2021). Compared to older homes, residences-built post 2000 had lower infiltration ratios during "fire days" (Liang, 2021).

Shrestha (2019) compared the impact of outdoor air pollution from wildfires to the air quality inside low-income housing to determine if indoor areas can be effectively used for PM2.5 protection. Twenty-eight homes were evaluated over two to seven days with air pollutants, including PM2.5, measured to characterize the relationship between indoor and outdoor concentrations. All the homes utilized natural ventilation, which was demonstrated to have a negative effect on indoor air pollutant concentrations due to infiltration of PM2.5 (Shrestha, 2019). The study also evaluated indoor factors such as exhaust stove hoods compared to recirculating hoods (Shrestha, 2019). Homes with exhaust stove hoods demonstrated an indoor/outdoor ratio of 49% less than homes using recirculating hoods and 55% less than homes using no stove hoods (Shrestha, 2019). This study revealed that low-income homes are significantly affected by environmental conditions, road proximity, and indoor behaviors (Shrestha, 2019).

3.3 Health Effects of PM2.5

Health effects of PM2.5 exposure from wildfire sources can range from relatively minor (respiratory irritation), to serious (asthma, heart failure, premature death) effects depending on the concentration, duration of exposure, and individual at risk (U.S. EPA, 2019). The youth (<18 years) are more sensitive to air pollution, and thus wildfire smoke (U.S. EPA, 2019). They spend more time outdoors, are typically more active, and consequently inhale more air during wildfire smoke season (Sacks et al. 2011). Older adults are more susceptible to short-term exposures to wildfire smoke due to an increased number of pre-existing conditions associated with age (U.S. EPA, 2009). Certain defense mechanisms decline with age, resulting in increased hospital admissions for older adults (U.S. EPA, 2009). The transitory population are those of lower socio-economic status at the community level. Transitory populations may not have consistent access to shelter within indoor environments.

Recently published studies on health outcomes in the northwest region of the United States associated with wildfire-sourced PM2.5 provide insight into the potential severity of wildfire exposure on public health. It is known that wildfire smoke can lead to increased hospital admissions for those with pre-existing respiratory health issues (Youssouf, 2014). Orr (2020) studied the long-term effects of wildfire smoke on the most susceptible population, the elderly. The study took place in Seeley Lake, MT, from July 31 to September 18, 2017, during heavy wildfire activity with a daily average PM2.5 concentration of 220.9 $\mu g/m^3$ (Orr, 2020). Health assessments were conducted in the community on 95 participants with an average age of 63 years (Orr, 2020). Follow-up assessments took place in 2018 and 2019 as well (Orr, 2020). The study revealed a significant decrease ($p < .05$) in lung function in 45.9% of the study population one year after the wildfire event, declining to 33.9% of the study participants two years after the wildfire event. (Orr, 2020). The study demonstrated that wildfire smoke has long-lasting effects on human health, and mitigation strategies are needed to reduce exposure (Orr, 2020).

Gan (2018) monitored the air quality from Washington wildfires to evaluate a potential association between adverse health outcomes and increased wildfire smoke exposure. The study was evaluated using a time-stratified case-crossover design and considered one wildfire season from July 1 to October 31, 2012 (Gan, 2018). Geographically weighted ridge regression, a spatial analysis technique that considers non-stationary variables (e.g., physical environmental factors, climate, etc.) and models the relationship between the non-stationary variables and an outcome of interest was used(Gan, 2018). The results showed that a 10 $\mu g/m^3$ increase in geographically weighted ridge regression smoke PM2.5 resulted in an 8% increased risk of asthma-related hospitalizations; however, chronic obstructive pulmonary disease (COPD) was not significantly associated with an increase in PM2.5 (Gan, 2018).

3.4 Low-Cost Air Quality Sensors

Low-cost sensors are used for monitoring atmospheric concentrations of particulate matter at relatively low costs when compared to NAAQS compliance EPA-approved monitors. Most of the low-cost sensors use optical particle counters or photoelectric sensors to detect particulate matter. Photoelectric sensors use infrared light and a photoelectric receiver to detect the presence of an object and to identify its size (AtGrating, 2022). The sensor is aligned with the light emitter, and a change in electrical signal will occur with any obstruction to the light (AtGrating, 2022). This is achieved with the photoelectric effect, where electrons of the passing particle absorb the photon energy (AtGrating, 2022). Optical sensors detect the state of the object and convert that into a light signal (AtGrating, 2022). When a particle passes through a beam of light, the light is scattered and can be measured to determine particle size (AtGrating, 2022). Low-cost sensors have become increasingly popular over recent years, with over 9,000 active PurpleAir aerosol monitors throughout the United States in 2020 (Tsai et al., 2020).

Correction factors for air quality monitoring equipment are essential for eliminating bias and improving the accuracy of the measurement. Barkjohn (2021) evaluated almost 12,000 24-hour averaged PM2.5 measurements collected from PurpleAir sensors, and Federal Reference Method (FRM) measurements from governmental stations across 16 states. This study revealed that PurpleAir sensors overestimate PM2.5 concentrations by an average of 40% (Barkjohn, 2021). A correction factor based on a simple linear regression and the addition of a factor to account for relative humidity reduced bias (Barkjohn, 2021). Overall, the root mean square error was reduced from 8 to 3 $\mu g/m^3$ (Barkjohn, 2021). The results show that the application of a correction factor may improve the accuracy of low cost sensors in air quality applications.

3.5 Portable Air Cleaner Effectiveness

Portable air cleaners (PACs) are designed to filter air in a room at a certain rate, as described by the clean air delivery rate (CADR). The CADR is the product of flow rate and filter efficiency. For example, a high-efficiency particulate air (HEPA) filter with 99.97% efficiency cleaning at 500 cubic feet per minute (cfm) would have a CADR of very close to 500 cfm. A HEPA filter in the portable air cleaner traps PM2.5 by drawing air through a high-efficiency filter.

The number of air changes per hour (ACH) represents how often the air is circulated in a specified room volume every hour. The greater the number of ACH, the greater the opportunity for particulate matter and other pollutants to be removed (AHM, 2021). The size of the room where the PAC is placed is an important variable and will influence the number of air exchanges made through the air cleaner. The Association of Home Appliance Manufacturers recommends the following equation for the largest room size that the PAC can be placed in during a wildfire event, depending on the number of air changes desired (AHAM, 2021):

$$Room\ Size\ (ft^2) = \frac{CADR\ (cfm)\ \times 60}{ACH\ \times Ceiling\ Height\ (ft)} \quad (1)$$

There have been several recent studies that evaluated the effectiveness of PACs in reducing indoor PM2.5 concentrations associated with wildfire events. Xiang (2021) studied the effectiveness of a PAC in apartment rooms, and a single-family home, by comparing the particulate matter concentration before and after the intervention of a PAC. The HEPA-PAC was left off for the first day of the study and then turned on in five out of the seven residences for the second day of the study (Xiang, 2021). A CADR of 116 cfm for dust, and 105 cfm for smoke was supplied by the manufacturer. Room sizes in the apartments and one house ranged from 581 ft^2 to 1905 ft^2, and year-built ranged from 1906 to 2019 (Xiang, 2021). The PAC was set to auto-mode, where it was able to switch speed settings (sleep, 1, 2, 3, turbo) based on measured concentrations (Xiang, 2021). Participants in this study were required to report indoor activities such as cooking, smoking, cleaning, candle burning, and window opening, along with the associated timeframe (Xiang, 2021). The study results revealed a 48%-78% decrease in the indoor PM2.5 concentration from using the PAC (Xiang, 2021). This study also suggests and gives relevant data to support the use of auto-mode PACs in the household (Xiang, 2021).

PACs have also been shown to control wildfire-sourced PM2.5 concentrations in the office setting (Stauffer, 2020). The effectiveness of a 3M Filtrete Ultra Clean PAC (FAP02-RS), with a MERV 13 rating, was evaluated by monitoring PM2.5 concentrations with two light scattering TSI Sidepack AM520 instruments each positioned in co-located offices; one with a PAC and one without (Stauffer, 2020). The indoor PM2.5 concentrations were compared with ambient PM2.5 mass concentrations obtained from a National Ambient Air Quality monitoring station located a few miles away (Stauffer, 2020). The results from this study revealed a 73% reduction in PM2.5 concentrations during working hours and a 92% reduction in PM2.5 concentrations during non-working hours (Stauffer, 2020). An office without a PAC was used as a matched control (Stauffer, 2020). The TSI Sidepacks overestimated the PM2.5 concentrations associated with wildfire smoke (Stauffer, 2020). A second outcome of this study was the publication of a ratio correction factor (Stauffer, 2020).

A summary of studies by Barn (2016) suggests that the application PACs should be considered a primary response mechanism to mitigate public exposures to wildfire smoke. The study evaluated health outcomes, such as endothelial function and inflammatory biomarker concentrations, in relation to the efficiency of particulate air filters to remove fine particulate matter from the indoor environment. Allen et al. found that indoor PM2.5 concentrations were reduced by 59% when using a HEPA-equipped PAC during landscape fire events. The 59% decrease in concentration, on average, was associated with improved endothelial function and decreased concentrations of inflammatory biomarkers (Allen, 2011). Correspondingly, research on residential air cleaner guidance shows that the best-documented health benefits come from reducing the amount of PM2.5 in homes (Harriman, 2019).

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Indoor exposures to PM2.5 particles of both indoor and outdoor origin account for about 70%, on average, of the total PM2.5 exposure throughout the United States (Fann, 2016). The study also supports the idea that portable air cleaners are the best way to reduce large amounts of PM2.5 if the central system does not use a MERV of 13 or higher filter efficiency (Harriman, 2019).

4. METHODS

4.1 Data Collection

4.1.1 Equipment

4.1.1.1 PurpleAir Sensors

Multiple PurpleAir-II-SD outdoor air quality sensors were used to measure real-time PM2.5 concentrations in this study. Although labeled as an outdoor sensor, the PurpleAir-II-SD is intended for outdoor and indoor use with an IP68 weather resistance rating. Built-in Wi-Fi allows for all data to be linked to an air quality map for easy data visualization across any smart device. An SD card is available in the instance of loss of connection or logging issues. The sensor utilizes two Plantower laser particle counters that are classified as class 1. Each particle counter stores particle sizes in five different bins: 0.3, 0.5, 2.5, 5.0, & 10µm (PurpleAir, 2022). For this study, we focused on the PM2.5 bin that includes particle sizes ~0.3µm to ~2.5µm. The counting efficiency of each particle counter is 50% at 0.3µm & 98% at 0.5µm (PurpleAir, 2022). The effective range of each particle counter is 0 to 500 $\mu g/m^3$, with a maximum range of 1000 $\mu g/m^3$ (PurpleAir, 2022). Each particle counter is independent of the other, with Channel A and Channel B. Each of the channels is then divided into two data sets, Primary and Secondary (PurpleAir, 2022).

In the PM2.5 bin, channel A & B Primary store mass concentration from count data for particles ~0.3µm to ~2.5µm for both "atmospheric" particles and "standard" particles (PurpleAir, 2022). The "atmospheric" and "standard" delineation is based on two different mass concentration conversion factors, to convert particle count to mass concentration. The "standard" particle entry data uses the "average particle density" of indoor particulate matter, while the "atmospheric" particle entry data uses the "average particle density" of outdoor particulate matter (PurpleAir, 2022). For this study, we used the Channel A Primary PM2.5 "atmospheric" particle entry data based on the characteristics of wildfire PM2.5 composition (PurpleAir, 2022).

4.1.1.2 UNbeaten Air Cleaner

Multiple UNbeaten Pet 300 PACs were also used for this study. This air cleaner is rated for an 800-square-foot room and can refresh air at 5x per hour on the high setting (UNbeatengroup, 2022). It is equipped with H13 True HEPA 5-stage filtration filters that remove 99.97% of airborne pollutants as small as 0.3 microns (UNbeatengroup, 2022). High-efficiency activated carbon accounts for roughly 80% of the filter, which has an estimated service life of 3-6 months (UNbeatengroup, 2022). For this study, each PAC was placed on setting 3 (high) and ran continuously for the length of the study. The clean air delivery rate (CADR), provided by the manufacturer, of the UNbeaten Pet 300 air cleaner is 177 cfm (UNbeatengroup, 2022).

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4.1.2 Sampling Setup

All wildfire smoke PM2.5 monitoring was conducted in a community located in the northwestern United States from August 27, 2021, through October 12, 2021. A total of nine PurpleAir-II-SD air quality sensors were strategically placed at three different facilities, identified by the local health department, and displayed in figure 1.

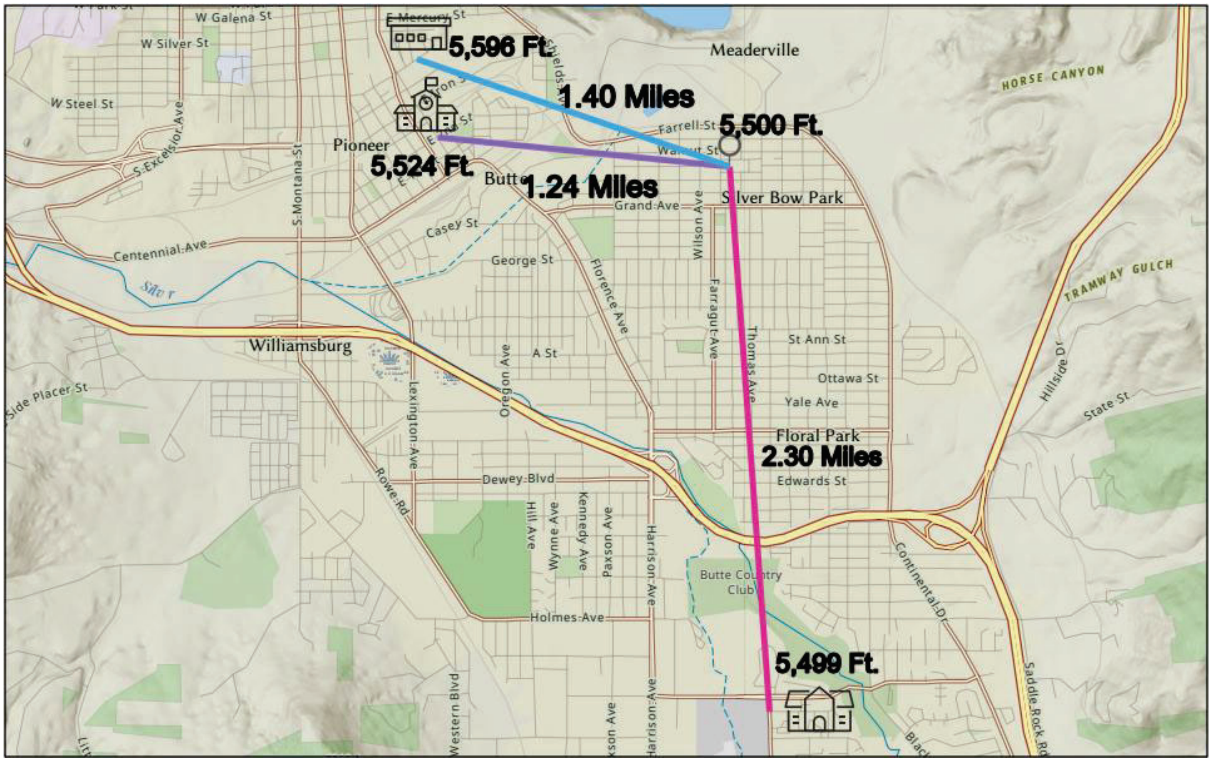

Figure 1. Facility Locations W/Elevation & Distance to NAAQS Air Station

Each facility was within four miles of the others and located less than three miles away from a NAAQS air station. Facility 1, Facility 2, and Facility 3 were equipped with three sensors each. The sensors were positioned close to standing head height (6 ft.) and attached to the wall. Two rooms were identified in each facility that were matched as close as possible based on volume, ventilation, occupancy, etc. One room in each of the facilities was equipped with an Unbeaten Pet 300 PAC. The PAC was placed on the opposite wall from the PurpleAir sensor, approximately 10 ft away at Facility 1, 15 ft away at Facility 2, and 40 ft away at Facility 3.

4.1.2.1 Facility 1

At Facility 1, a homeless shelter, two 124 ft^2 (992 ft^3) rooms with one window each were selected. A PurpleAir monitor was positioned on the wall furthest from the door to the hallway in each room. A portable air cleaner was placed 8 ft from the floor and 10 ft from the PurpleAir in room 2. Both rooms were located adjacent to each other, and were the furthest away from the indoor kitchen and cafeteria area. The third sensor was hung on the exterior of the building, directly outside of the two rooms and between their respective windows.

Figure 2. PurpleAir Setup @ Facility 1

Figure 3. PAC Setup @ Facility 1

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Figure 4. Exterior Sensor Setup @ Facility 1

4.1.2.2 Facility 2

At Facility 2, a senior adult assisted living complex, two 460 ft^2 (3680 ft^3) rooms with two larger windows each were selected. Both rooms included a bedroom, bathroom, and closet space in the layout. A PurpleAir monitor was positioned on the wall between the bedroom and the bathroom, in each room. A portable air cleaner was placed on the ground level and 15 ft from the PurpleAir in room 2. The third sensor was placed directly outside the entrance to the building.

Figure 5. PurpleAir Setup @ Facility 2

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Figure 6. PAC Setup @ Facility 2

Figure 7. Exterior Sensor Setup @ Facility 2

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4.1.2.3 Facility 3

At Facility 3, a school building, two 1,240 ft^2 (14,880 ft^3) rooms with multiple windows each were selected. A PurpleAir monitor was positioned on the wall midway between the room entrance and the windows, in each room. A portable air cleaner was placed 8 ft from the floor and 40ft from the PurpleAir in room 2. The third sensor was placed at an elevated level, on the exterior of the building. Each room was largely occupied (12 – 16 persons) during the weekdays, and empty on the weekends.

Figure 8. PurpleAir Setup @ Facility 3

Figure 9. PAC Setup @ Facility 3

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4.2 Data Analysis

4.2.1 Smoke Day Qualification

For this study, only data collected during wildfire events where the NAAQS Air Monitoring Station measured ambient PM2.5 concentrations of 50 $\mu g/m^3$ or greater during a 1-hour average, were considered. These were defined as "smoke days." For Facility 1, 11 "smoke days" were considered, corresponding to n=264 hourly concentrations at each sensor location. For Facility 2, 10 "smoke days" were considered, corresponding to n=240 hourly concentrations at each sensor location. For Facility 3, 11 "smoke days" were considered, corresponding to n=264 hourly concentrations at each sensor location. The PM2.5 concentrations measured at each facility were also compared to hourly data from the local NAAQS air monitoring station. A threshold was set to trim the data at ≥5 $\mu g/m^3$ according to the county air station. This threshold trimmed the data to n=234, n=215, and n=234 for Facility 1, Facility 2, and Facility 3, respectively.

4.2.2 Correction Factor

All data, either from the PurpleAir Map or SD cards, was downloaded as 1-hour averages measured in $\mu g/m^3$. After comparing concentration data from the exterior of each of the facilities to the local air monitoring station data, it was evident that the PurpleAir sensors were overestimating the ambient PM2.5 concentrations. A Bland-Altman Plot was used to visualize the difference in concentration measurements between the uncorrected outside measurements and the local air monitoring station measurements. Based on this overestimation, the correction factor equation from Barkjohn (2021) was applied to all data points, excluding the the local NAAQS air monitoring station data.

$$Corrected\ PM2.5\ \left(\frac{ug}{m^3}\right) = 0.524 * \left(PA\ PM2.5\ \left(\frac{ug}{m^3}\right)\right) - 0.0862 * (RH) + 5.75 \tag{2}$$

where PA is PurpleAir sensor data, and RH is relative humidity

4.2.3 Statistical Analysis

Descriptive statistics were used to summarize mean PM2.5 concentrations for each sensor location at each facility. A time series plot was generated at each of the facilities to visually compare the PM2.5 concentrations at each of the sensor locations. The average percent differences were then calculated for: outside vs. inside w/o filter, inside w/o filter vs. inside w/ filter, and outside vs. inside w/ filter at each of the facilities. The percent differences were further categorized based on their PM2.5 range and corresponding Air Quality Index (AQI) description. The total theoretical time spent (hours) in each of the PM2.5 ranges was then calculated for each monitoring location at each facility.

Since data were not normally distributed, a Levene's test was used to test for equal variances between sensor locations at each facility. The null hypothesis was that all variances are equal, and the level of statistical significance was set at α = 0.05. A Welch's one-way ANOVA Test, and Games-Howell ANOVA with pairwise comparisons and simultaneous tests were performed for mean differences between indoor w/o PAC, indoor w/ PAC, and ambient PM2.5 concentrations. The null hypothesis was that all means are equal, and the level of statistical significance was set at α = 0.05. Finally, Chi-Square Goodness-of-Fit tests were performed on concentration data from each sensor location at each of the three facilities. The expected counts are outdoor concentration data, and the observed counts are

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indoor “no filter” and indoor “yes filter”, separately. The null hypothesis was that there was no difference between the expected counts and the observed counts.

5. RESULTS

The mean 1-hour averaged, trimmed, and corrected data for each of the “smoke days” were categorized based on facility and sensor location. These mean concentrations for each sensor location at each facility are summarized in Table 1, with raw 1-hour concentration data in Appendix A. As shown in the table, the average outdoor concentration at Facility 1 was 42.17 $\mu g/m^3$, the average indoor “no filter” concentration was 31.52 $\mu g/m^3$, and the average indoor “yes filter” concentration was 22.67 $\mu g/m^3$. The average outdoor concentration at Facility 2 was 44.79 $\mu g/m^3$, the average indoor “no filter” concentration was 35.88 $\mu g/m^3$, and the average indoor “yes filter” concentration was 21.95 $\mu g/m^3$. The average outdoor concentration at Facility 3 was 42.65 $\mu g/m^3$, the average indoor “no filter” concentration was 37.20 $\mu g/m^3$, and the average indoor “yes filter” concentration was 30.66 $\mu g/m^3$. The measured outdoor concentration differences between each of the facilities can be attributed to geographic location. The measured indoor concentration differences between each of the facilities can be attributed to room size (sqft.), smoke infiltration, occupancy, and other indoor particulate matter contributors. Time-series plots for each sensor location, at each of the three facilities, are provided in Appendix B.

The average percent difference between each 1-hour averaged concentration was calculated for: outdoors vs. indoors “no filter”, inside “no filter” vs. inside “yes filter”, and outside vs. inside “yes filter” at each of the facilities. Summary average percent difference data are provided in Table one.

Table 1. Summary Average Percent Differences at each Facility

Facility #	Outdoor vs. Indoor “no filter”	Indoor “no filter” vs. Indoor “yes filter”	Outdoor vs. Indoor “yes filter”
Facility 1	-22.12 %	-34.36 %	-50.03 %
Facility 2	-15.00 %	-35.92 %	-47.37 %
Facility 3	-1.45 %	-15.67 %	-21.25 %

The number of ACH were calculated using equation one above, and illustrated in table two below. A CADR of 176.57 cfm was given by the manufacturer, and used in the calculations. The ACH presented below ignore any mechanical or natural ventilation in the rooms.

Table 2. Summary ACH for Rooms at each Facility

Facility #	Room Volume (ft^3)	CADR (cfm)	ACH
Facility 1	992	176.57	10.68
Facility 2	3,680	176.57	2.88
Facility 3	14,880	176.57	0.71

The US EPA and Montana Department of Environmental Quality provide public health advisories or levels of concern based on measured PM2.5 concentrations in community airsheds. The color-coded advisories are illustrated below. The measured duration (in hours) at each of the EPA PM2.5 ranges is illustrated for each facility in Figures 10 - 12. Note that the total time is only based on applicable “smoke days” data.

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- $0 – 12.0\ \mu g/m^3$ (Good)
- $12.01 – 35.5\ \mu g/m^3$ (Moderate)
- $35.51 – 55.5\ \mu g/m^3$ (Unhealthy for Sensitive Groups)
- $55.51 – 250.5\ \mu g/m^3$ (Unhealthy/Very Unhealthy)

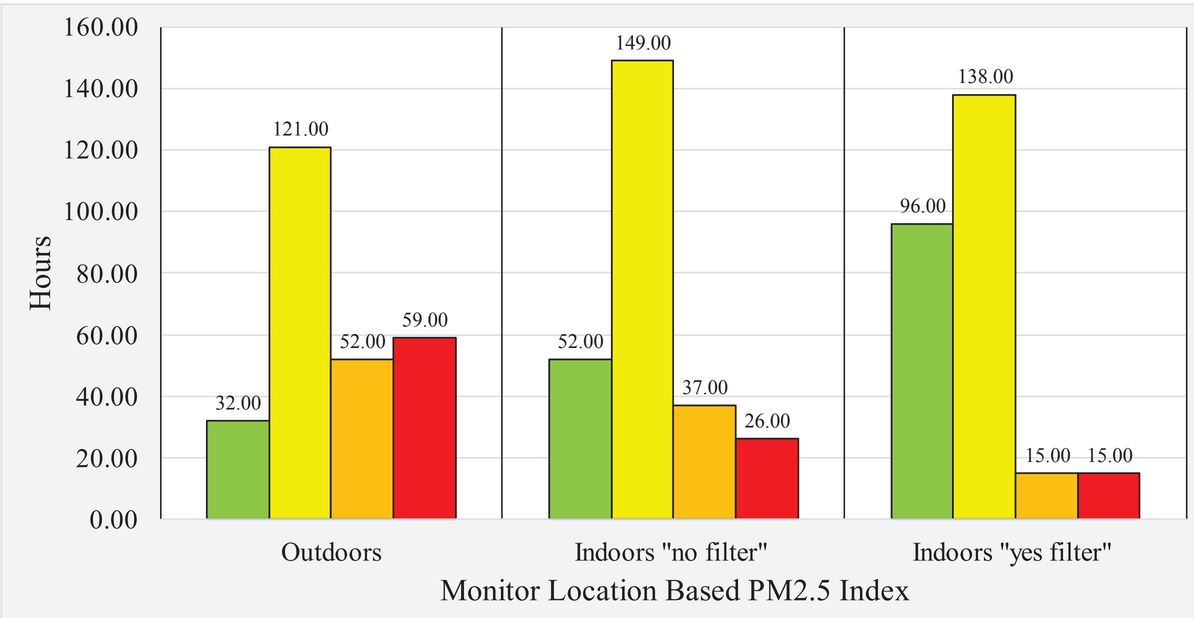

Figure 10. Facility 1 - Time Spent in Each AQI Description Based on Sensor Location

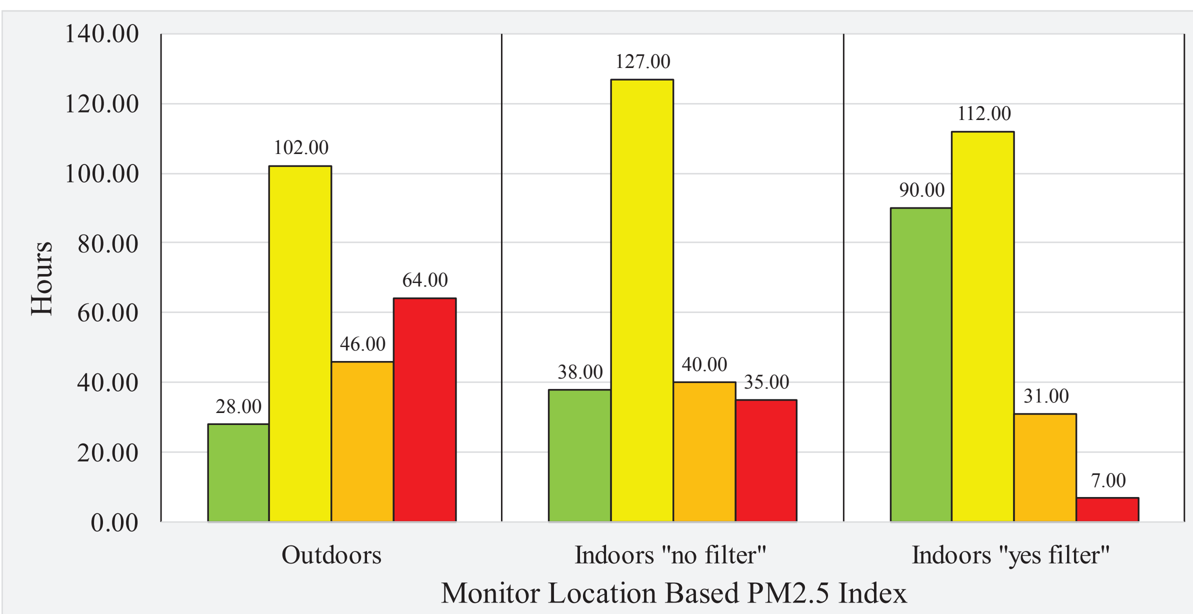

Figure 11. Facility 2 - Time Spent in Each AQI Description Based on Sensor Location

https://doi.org/10.5281/zenodo.8105756

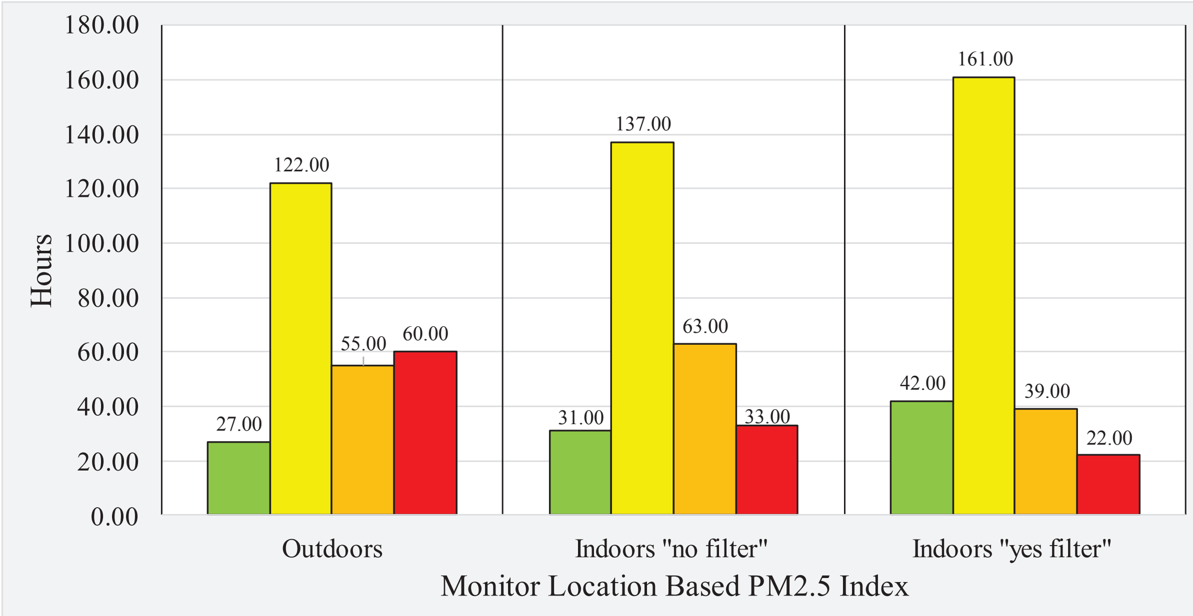

Figure 12. Facility 3 - Time Spent in Each AQI Description Based on Sensor Location

A Levene's test was used to determine if there was homogeneity of variance between the sensor locations at each of the three facility locations. At facility 1, the outdoor PM2.5 concentrations had a significantly different standard deviation ($p < .05$) than both indoor concentrations. At facility 2, the indoor "yes filter" concentrations had a significantly different standard deviation ($p < .05$) than the indoor "no filter" and outdoor concentrations. At facility 3, the outdoor PM2.5 concentrations had a significantly different standard deviation ($p < .05$) than both indoor concentrations.

At least one variance was different for each sensor location at each of the three locations. As a result, a one-way ANOVA was used along with the Games-Howell test to compare combicountries of statistical group differences between the sensor locations at each of the three facility locations. At facility 1, each sensor location was grouped separately, corresponding to PM2.5 concentration means that are all significantly different ($p < .05$). At facility 2, each sensor location was grouped separately, corresponding to PM2.5 concentration means that are all significantly different ($p < .05$). At facility 3, the outdoor sensor and indoor "no filter" sensor were grouped together, while the indoor "yes filter" sensor had a PM2.5 concentration mean that was significantly different ($p < .05$). Interval plots for Facility 1, Facility 2, and Facility 3 are provided below in Figure 13, Figure 14, and Figure 15 respectively.

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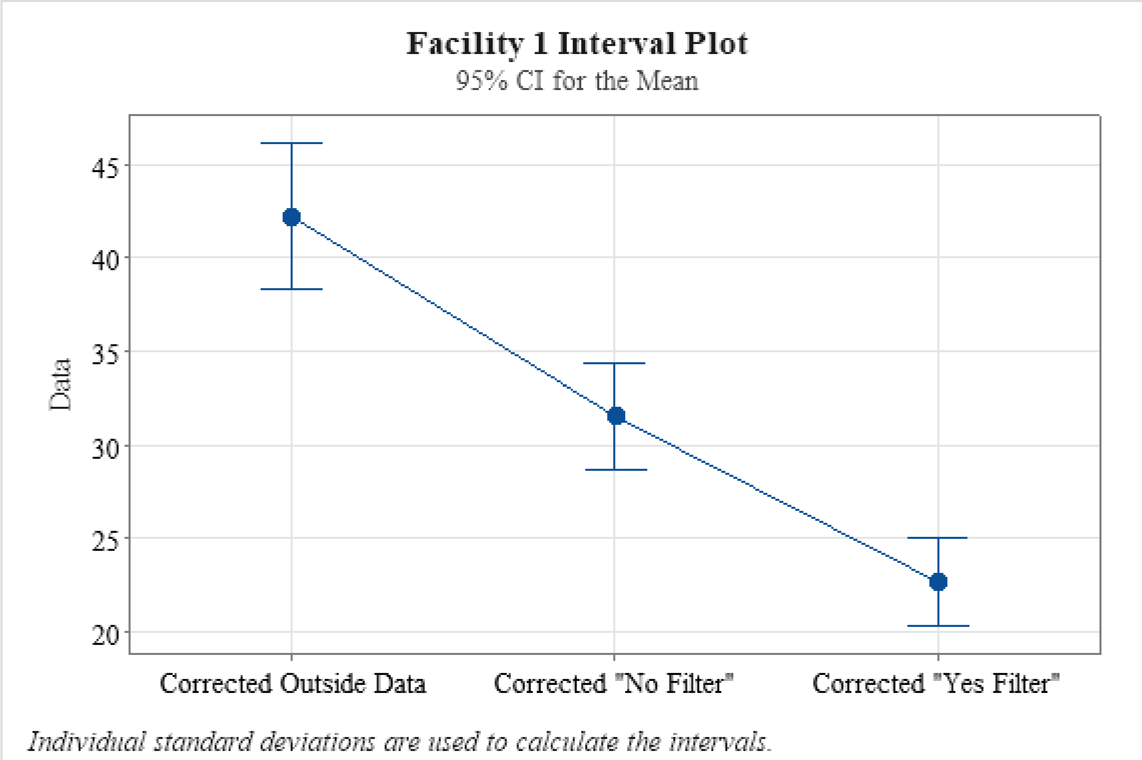

Figure 13. Facility 1 Interval Plot

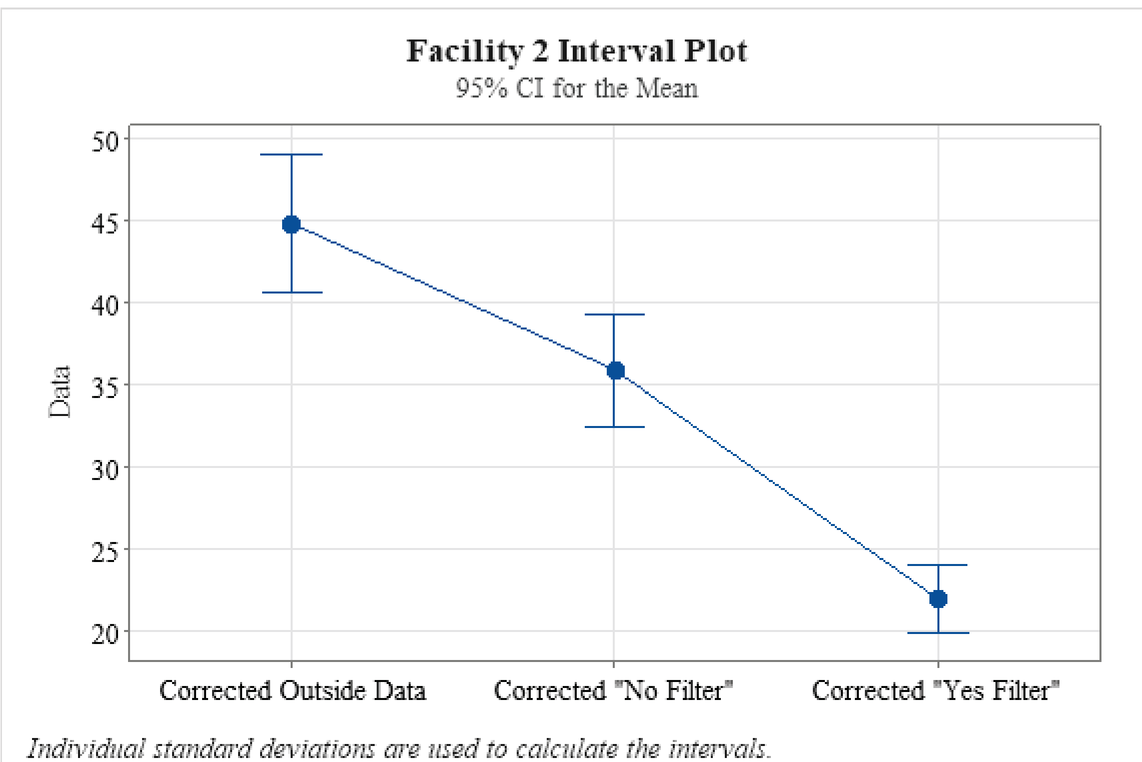

Figure 14. Facility 2 Interval Plot

https://doi.org/10.5281/zenodo.8105756

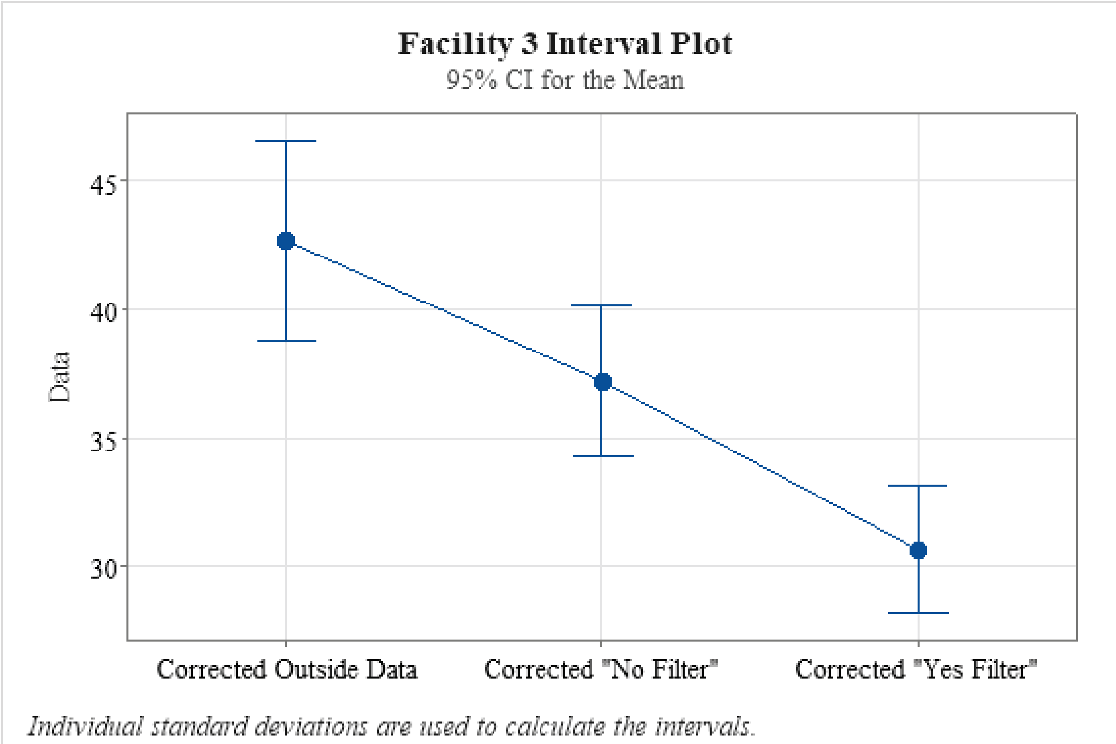

Figure 15. Facility 3 Interval Plot

A Chi-Square Goodness-of-Fit test was performed on concentration data from each sensor location at each of the three facilities. The expected counts at each of the facilities were outdoor concentration data, while the observed counts at each of the facilities were indoor concentration data from either "no filter" or "yes filter" designated rooms. Each test resulted in a significant discrepancy in fit between the observed and expected values. The plots for Facility 1, Facility 2, and Facility 3 are provided below in Figures 16 - 21.

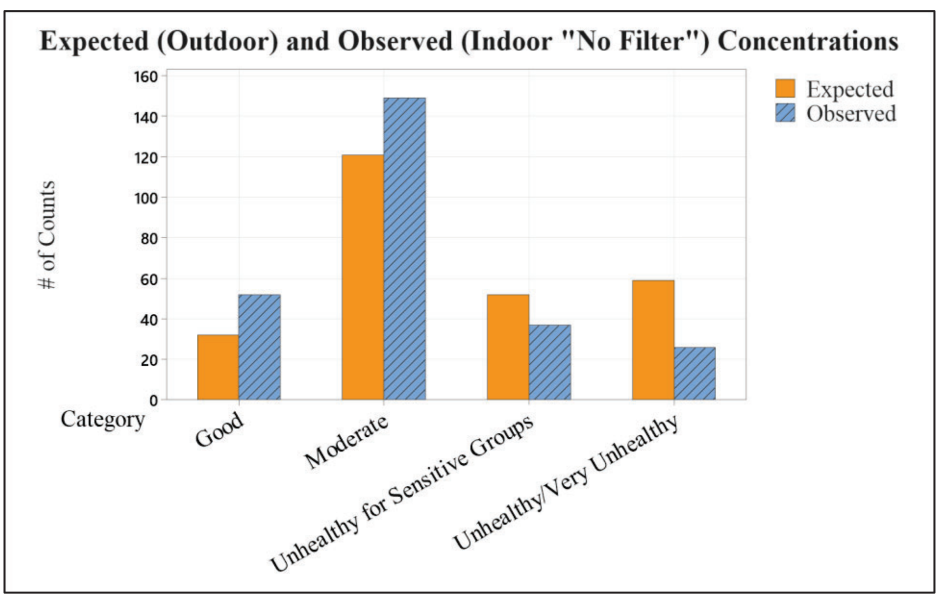

Figure 16. Facility 1 Expected (Outdoor) and Observed (Indoor "No Filter") Concentrations

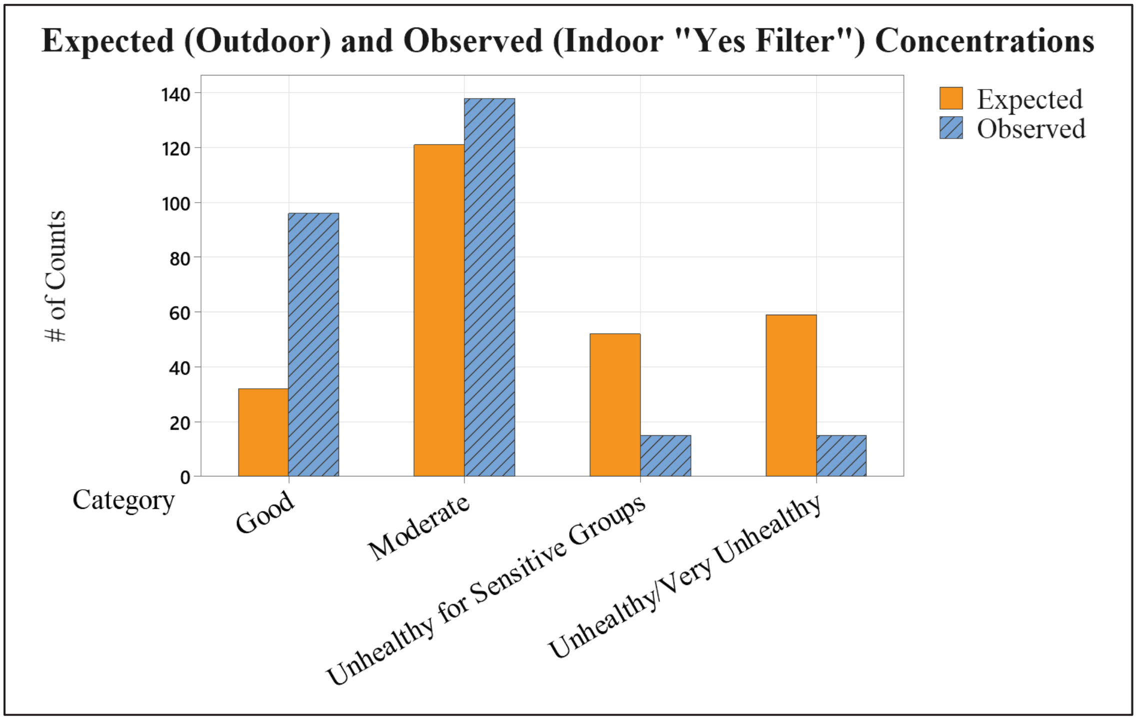

Figure 17. Facility 1 Expected (Outdoor) and Observed (Indoor "Yes Filter") Concentrations

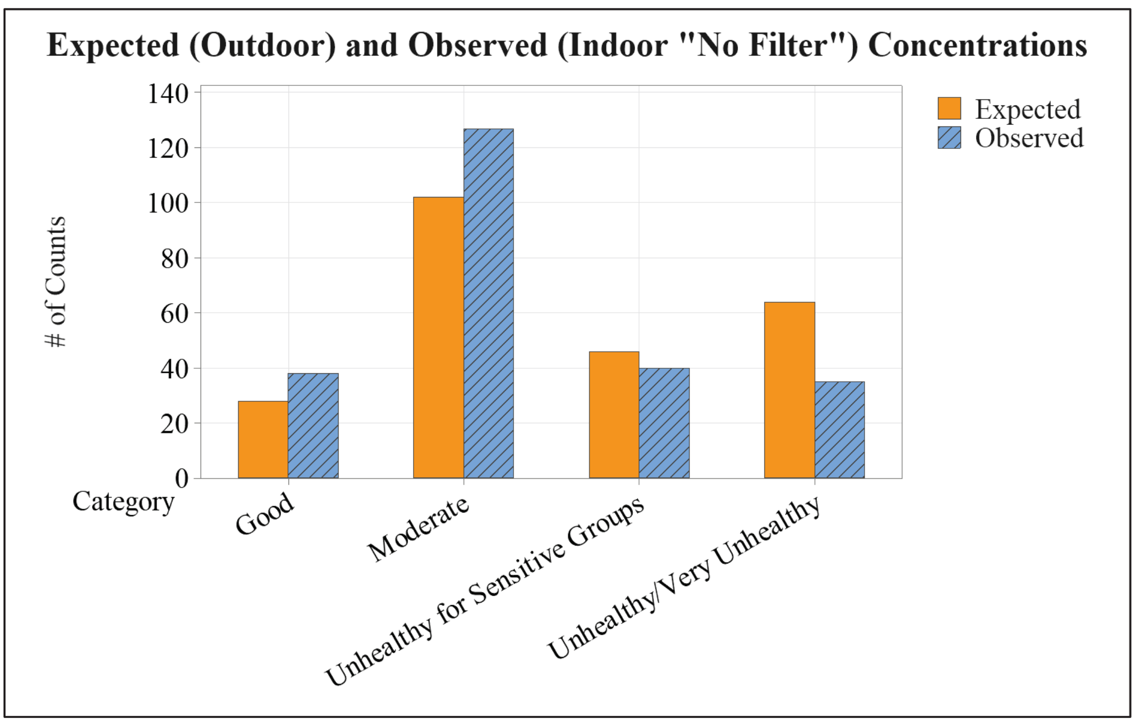

Figure 18. Facility 2 Expected (Outdoor) and Observed (Indoor "No Filter") Concentrations

https://doi.org/10.5281/zenodo.8105756

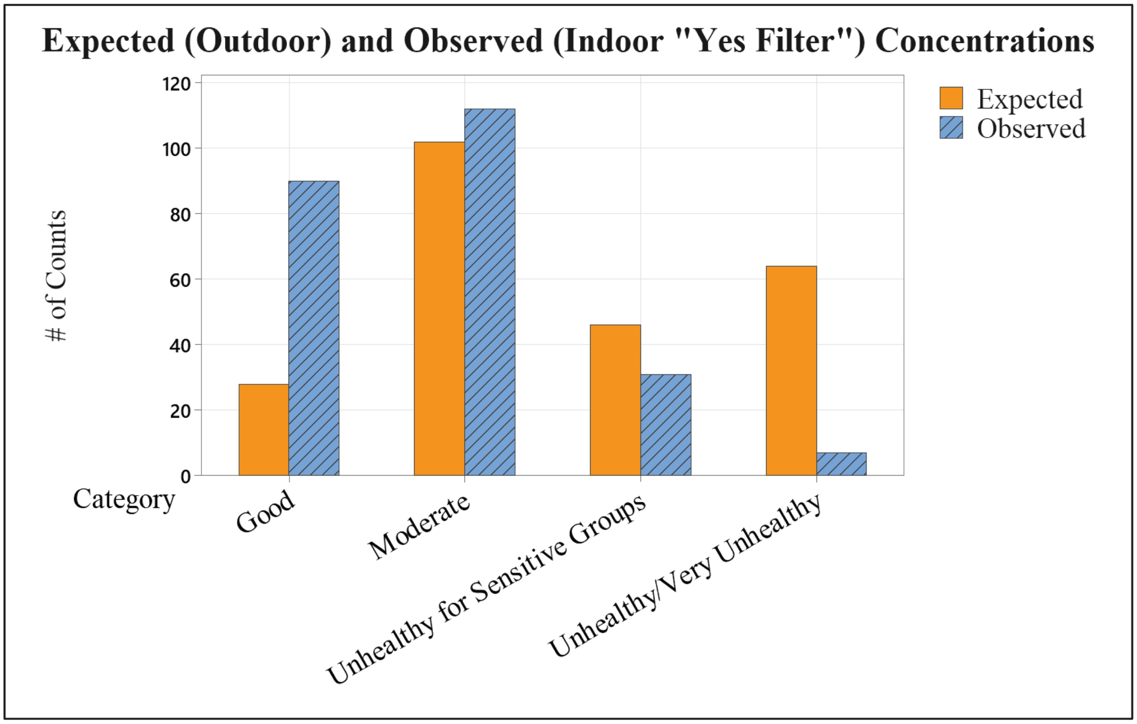

Figure 19. Facility 2 Expected (Outdoor) and Observed (Indoor "Yes Filter") Concentrations

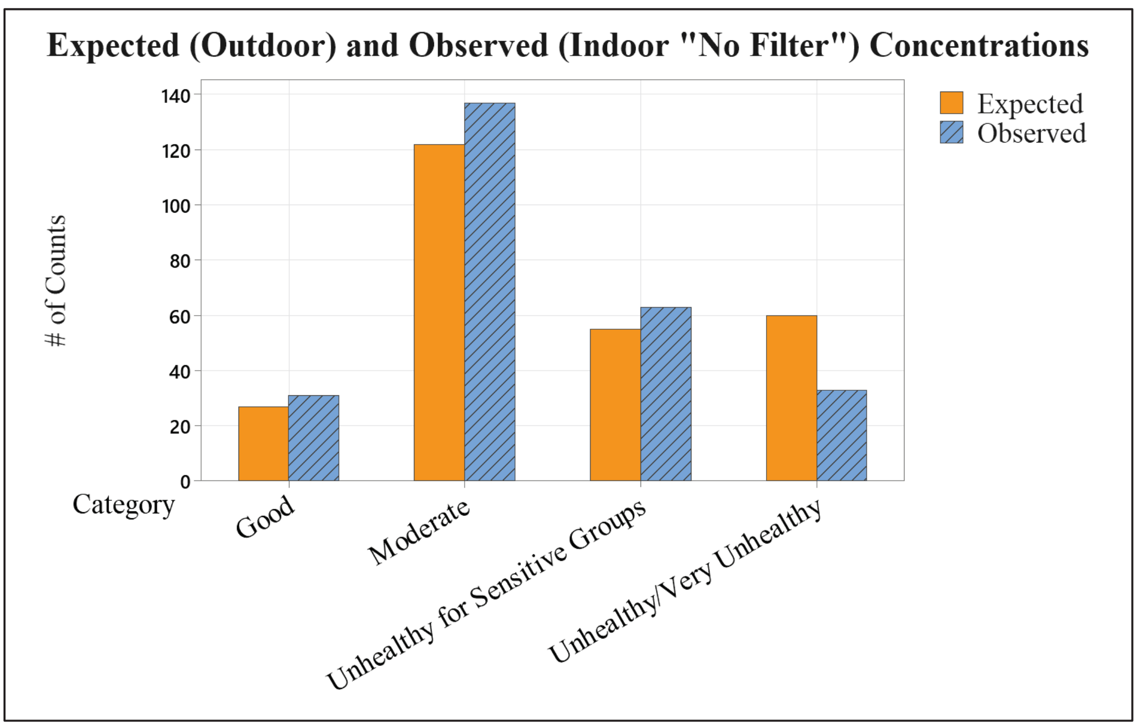

Figure 20. Facility 3 Expected (Outdoor) and Observed (Indoor "No Filter") Concentrations

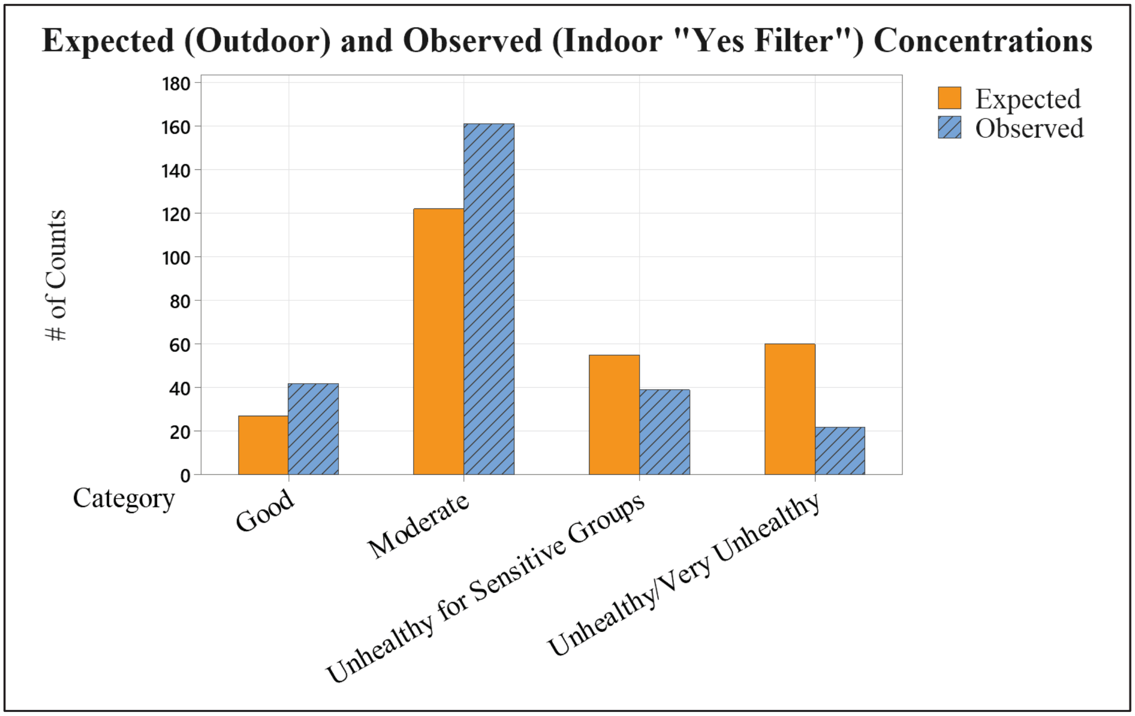

Figure 21. Facility 3 Expected (Outdoor) and Observed (Indoor "Yes Filter") Concentrations

6. DISCUSSION

The primary objective of this study was to evaluate the effectiveness of staying indoors during a wildfire event and staying indoors with a PAC during a wildfire event. The first aim was to compare the mean PM2.5 concentrations at each sensor location, at each of the three facilities. The results indicated that the average outdoor concentrations at each facility were within 6% of each other.

An assessment of the average percent differences between each facility, and corresponding sensor locations revealed that as room volume at each facility increased, the percent difference in PM2.5 concentrations between outdoor and indoor “no filter” sensor locations decreased. Similarly, as room volume at each facility increased, the percent difference in PM2.5 concentrations between outdoor and indoor “yes filter” sensor locations decreased. Overall, a decrease in PM2.5 concentrations was seen while being indoors with or without a PAC.

The second aim was to assess the total amount of time that each population group had spent in each EPA PM2.5 concentration range. Comparing the outdoor and indoor “yes filter” sensor locations at Facility 1, the number of hours spent in the unhealthy/very unhealthy range was decreased from 59 to 15 (74.58% decrease), while the number of hours spent in the good/moderate range was increased from 153 to 234 (52.94% increase). At facility 2, the number of hours spent in the unhealthy/very unhealthy was decreased from 64 to 7 (89.06% decrease), while the number of hours spent in the good/moderate range was increased from 130 to 202 (55.38% increase). At facility 3, the number of hours spent in the unhealthy/very unhealthy was decreased from 60 to 22 (63.33% decrease), while the number of hours spent in the good/moderate range was increased from 149 to 203 (36.24% increase).

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An assessment of the ACH for each room size at facility 1, facility 2, and facility 3 revealed that the UNbeaten PAC was only large enough for the rooms at facility 1 based on a recommendation of 5 ACH minimum (Salimifard, 2020). During wildfire events, the Association of Home Appliance Manufacturers recommends an ACH of 7.5 (AHAM, 2021). Having a higher ACH presents greater opportunities for air pollutants to be removed, resulting in cleaner indoor air (AHAM, 2021).

The relative risk of chronic obstructive pulmonary disease (COPD), lung cancer in adults (LC), ischemic heart disease (IHD), acute lower respiratory infection in children (ALRI), and stroke with PM2.5 exposure has been reported (Burnett, 2014). This information is useful when comparing the time spent in each EPA PM2.5 concentration range, with possible health outcomes. For example, reducing an exposure from 100 ug/m3 to 35.5 ug/ m3 would reduce the relative risk of lung cancer from 1.55 to 1.25 (Burnett, 2014).

6.1 Study Limitations

Each of the facilities are equipped with ventilation systems that are operated/maintained independently. A facility built in recent years with a well-maintained ventilation system will perform more favorable than an old facility with a poorly maintained ventilation system.

Similarly, the infiltration of wildfire-induced PM2.5 can depend on leaving doors and windows open, and the seal around the doors and windows. The occupants of each room at each facility were urged to keep the windows and doors to the exterior closed as much as possible. During regular check-ins, it was noted that the occupant in the indoor "no filter" room at Facility 2 was opening the window throughout the day. There were no other incidents for open windows at any of the other sensor location.

The number of occupants at each facility also differed, with 1-2 at Facility 1, 1-2 at Facility 2, and 12-16 at Facility 3. Facility 1 was only occupied during the night, Facility 2 was occupied during the day and night, and Facility 3 was only occupied during the day.

7. CONCLUSION

This study evaluated the effectiveness of staying indoors during a wildfire event and staying indoors with a PAC during a wildfire event. Previous studies have revealed that portable air cleaners are an effective intervention to decrease the concentration of wildfire-induced PM2.5 indoors. These results suggest that even if a portable air cleaner is not available, staying indoors is still an effective option to decrease wildfire PM2.5 exposure. The use of a PAC greatly reduces the amount of time an occupant is exposed to unhealthy/very unhealthy concentrations of wildfire-induced PM2.5. The PAC performed most efficient at or below its designed room square footage, but still offered a smaller decrease in PM2.5 for the larger square footage.

In terms of the vulnerable population, the indoor PM2.5 concentration should be at or below 35.5 $\mu g/m^3$, as to stay below concentrations that are unhealthy for sensitive groups. Further research should be performed to include a larger number of facilities and sensor locations, potentially including sensors in ventilation/HVAC systems. A potential limitation that may have influenced the PM2.5 concentrations reported is the amount of indoor PM2.5 that was produced during the study period.

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APPENDIX A

Raw 1-hour averaged, trimmed, and corrected concentration data for each sensor location at each facility during all "smoke days" are provided here: Appendix A - Raw Data

APPENDIX B

Time-series plots for each of the three facilities, each including 1-hour averaged, trimmed, and corrected concentration data for each sensor location during all "smoke days" are shown below:

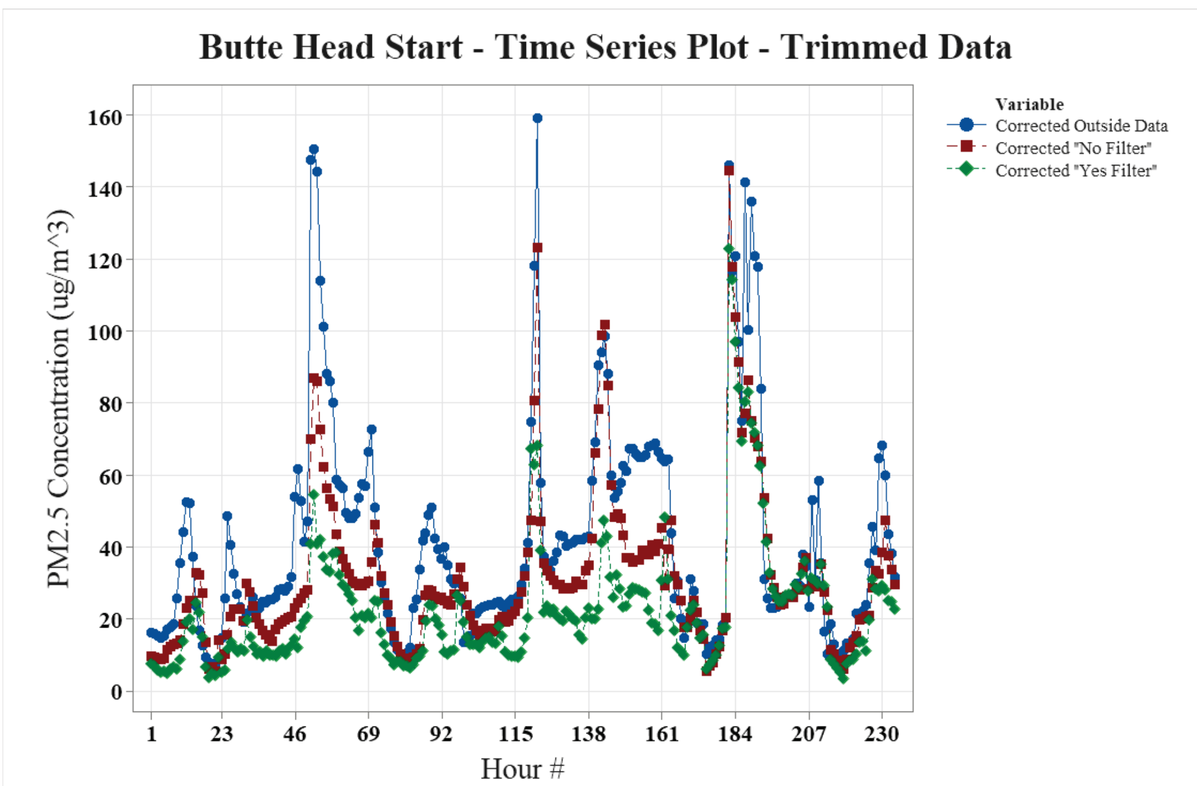

Figure 22. Time Series Plot - Facility 1 - Trimmed Data

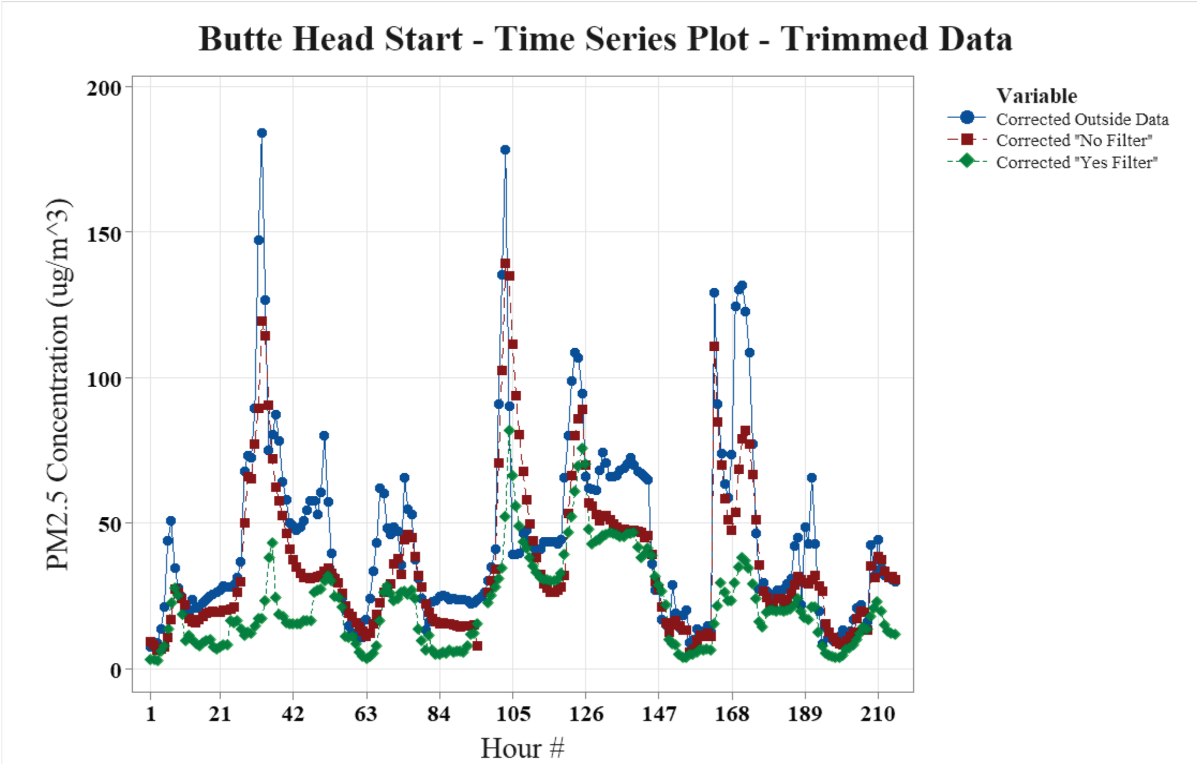

Figure 23. Time Series Plot - Facility 2 - Trimmed Data

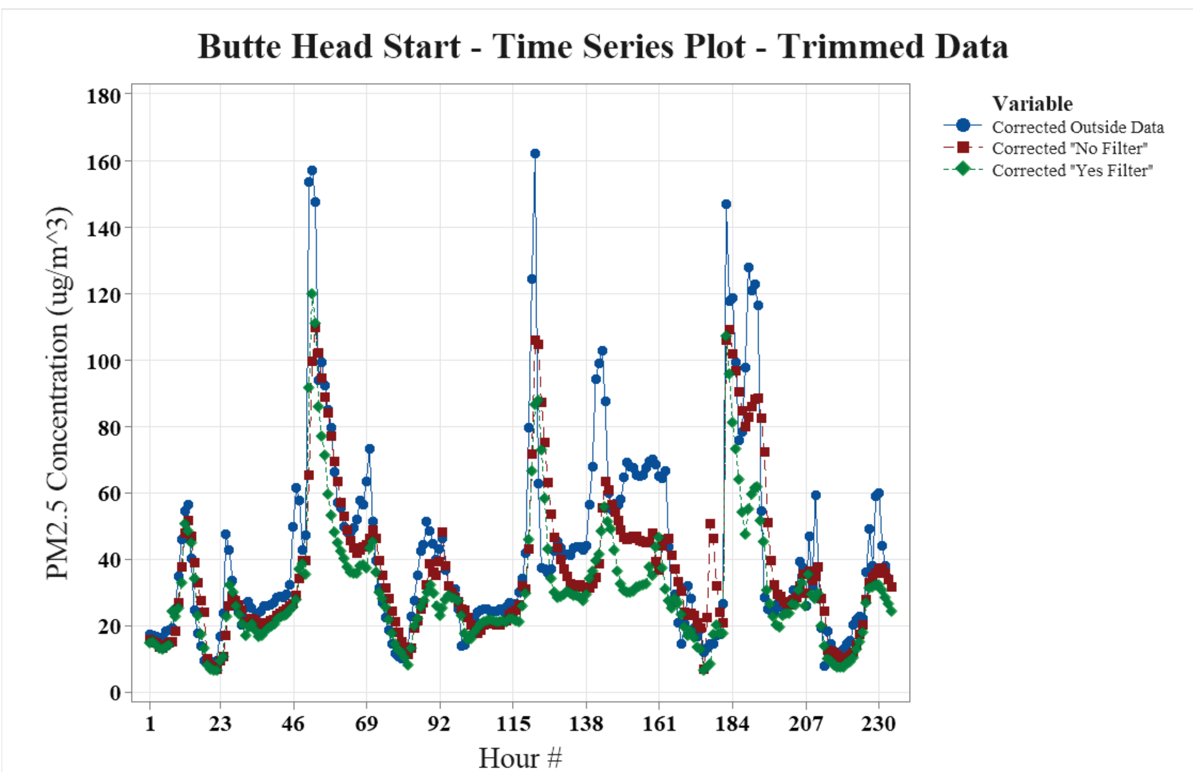

Figure 24. Time Series Plot - Facility 3 - Trimmed Data

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MAIN AUTHOR

Mr. Layne Willis is a graduate student at Montana Tech. Layne earned his bachelor's degree in civil engineering at MSU and, recently, his master's degree in industrial hygiene. Layne worked with Drs. Dan Autenrieth and Julie Hart in the Department of Safety, Health, and Industrial Hygiene. Layne completed his research on the effectiveness of low-tech, low-cost air purification systems for vulnerable populations in the Butte area during wildfire smoke events.

Working with the Bute Silver-Bow Health Department, the team identified three groups: senior citizens at the Springs, the young at Butte Head Start, and the underprivileged at the Butte Rescue Mission. Layne had to first meet his population on a personal level. He placed air monitors and air purifiers in specific locations for two months. Air quality measurements were taken during the two-month smoke season in residences with air purifiers. Findings revealed that staying indoors reduces exposure, and the air purifiers further reduced exposure to harmful air pollutants. The research provides evidence of effective and affordable interventions for disadvantaged and vulnerable citizens.

CITATION:

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Tactical exercises and verification of the effectiveness of crisis planning in the Moravian-Silesian Region. A case study from the Czech Republic

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KEYWORDS

Crisis preparedness
Tactical exercise
Trauma plans
Risk
Extraordinary event

ABSTRACT

Background: Crisis preparation in healthcare facilities should address and resolve both internal and external medical situations. This includes handling the admission of huge numbers of patients during catastrophic disasters, for example. Simultaneously, the management of accidents and disturbances within healthcare facilities, such as fires, power outages, lift functionality, evacuations, and so on, should be managed not only in collaboration with the integrated rescue system, but also in collaboration with higher territorial self-government units, namely regional authorities. The tactical exercises carried out by all components of the rescue system and their preparedness, which frequently show weak places, are one method of testing the efficacy of crisis planning.

Aim: Five tactical exercises were held in the Moravian-Silesian Region from 2015 to 2019 as part of the integrated rescue system's readiness, with the goal of testing the procedures of rescue work in road and rail accidents with a large number of injured people, and then testing the readiness of medical facilities to provide fast, effective, smooth, and well-organized medical care ("launch of the Traumatology Plan").

Datafile and Methods: For the tactical drills, five health care institutions created by the region were chosen. These were volunteer organizations that provided acute inpatient and outpatient care. After reviewing all tactical exercises, it was discovered that communication difficulties, insufficient marking of medical material, the medical team or interveners, and stations were the weak points. Human elements, as well as building and organizational measures in hospitals, proven to be troublesome.

Conclusion: The exercise tested the efficiency and coordination of the integrated rescue system's components, the ability of firefighters to provide first aid to affected people and carry out rescue and recovery work, and revealed the so-called weak points in the trauma plan's activation.

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1. INTRODUCTION

The world's population is constantly encountering, and will probably continue to encounter, extraordinary events that often have a negative impact not only on its activities but also on existence itself, and that includes the consequences of adverse effects on the environment, failure of technology, the economy, and, last but not least, human error. Companies try to prevent the occurrence of extraordinary events or minimize their consequences. The Ministry of the Interior of the Czech Republic has created the Population Protection Concept for 2020 with a view to 2050 (iHETA, 2019). A very important element in the protection of the population is also the level of health care provided by the given country, which is an indicator of its maturity and is determined according to the gross domestic product of the country.

Inpatient medical facilities prepare for emergencies and crisis situations as part of risk management and by creating plans such as trauma plans, pandemic plans, or evacuation plans. In the Czech Republic, after 1989, extensive trauma centers and emergency services were established, which are prepared for the occurrence of extraordinary events. Their task is to eliminate the medical consequences of a mass disaster in cooperation with the components of the integrated rescue system. Mastering the treatment of these serious conditions is ensured mainly by means of prepared trauma plans. These plans are developed for the mass admission of people with various types of disabilities, such as trauma, contamination (biological or chemical), substance intoxication, burns, and radiation effects. Traumatological plans define the tasks and methods of management in the healthcare sector with a focus on activities in the event of mass accidents, describe the activities of the operational centers of the medical rescue service, and provide contacts for healthcare services and facilities (hospitals). It also contains the impacts of selected extraordinary events on the health of the population, including the forces and means for ensuring health care (OSRI, 2019).

2. LEGAL REQUIREMENTS IN THE CZECH REPUBLIC

The obligation to prepare a trauma plan follows the current legislation of the Czech Republic. Inpatient medical facilities and facilities that provide one-day care are required to prepare a trauma plan, in which they adjust the set of measures that are applied in the event of a mass disaster, and to update it at least once every two years. The facility submits one copy of the plan to the relevant administrative authority (regional office, department of health) within 30 days from the date of its processing or updating. Processing is based on local conditions and possibilities and the results of discussing them (Act on Health Services 2011, 47, p. 4758).

2.1 The Trauma Plan

The content of the trauma plan is precisely defined by the applicable legislation and entails three parts: basic, operative, and auxiliary. The basic part defines, in addition to basic data about the organization (hospital), an overview and evaluation of possible internal and external sources of risks and threats to the medical facility and the definition of the provider's scope of activity. The operative part defines the procedures for the implementation of measures for the reception of a mass accident, cooperation with the medical rescue service, and individual workplaces in an inpatient medical facility. Part of the content is also an overview of connections and how to ensure the protection of workers' health. The auxiliary part contains overviews of, for example, concluded contracts with supplier institutions, a list of medical devices, medicines, and medical personnel, labeling principles, records, and other related documents.

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However, it is possible to state succinctly that the trauma plans developed by inpatient medical facilities define potential external and internal risks that are present in or close to their organization and may pose a threat to the occurrence of extraordinary events or accidents. They define the contact points for communication with the integrated rescue system, including the characteristics of possible types of injuries and their treatment in the mentioned facility and the possible number of patient admissions in the time horizon. In the final part of the plans, personnel provision, material and technical equipment in the event of an emergency, and the contractual provision of companies in the event of a power outage are specified. Competences are also listed, whether from management to mini-trauma teams in operating and procedure rooms.

Prepared, regularly updated, and reviewed (e.g., tactical exercises) trauma plans must respect and fulfill the currently valid state legislation; however, some risks may still be underestimated. In most cases, existing emergency plans focus on mechanical risks, but it is also worth considering chemical, biological, and radiation risks, which can overload inpatient medical facilities. Threats with biological weapons began to appear in the world (e.g., the war conflict in Ukraine), and with them came preparations for a large intake of wounded contaminated with dangerous substances. An important project was, for example, TOXI-triage, which was based on the concept of dual use, namely multipurpose applications for our technologies within general emergency medicine (toxicity) and the environment. The Horizon 2020 project was also focused on the community and its rescue (Toxi-Triage, http://www.toxi-triage.eu/). The Fire and Rescue Service of the Moravian-Silesian Region took part in this international project.

2.2 Definition of an inpatient medical facility and its function for crisis planning

Medical facility means premises intended for the provision of medical services. Health services can be divided according to the form of health care provided in health facilities into ambulatory, one-day, inpatient, and health care provided in the patient's own social environment (e.g., visiting service, home care, artificial pulmonary ventilation, which can be provided as part of the provision of home care), and subsequently the type of care. Bedside care is understood as (Act on Health Services 2011, 9, p. 4734):

> *health care that cannot be provided on an outpatient basis and requires the hospitalization of the patient for its provision*.

This care must be provided as part of continuous operation. Accurate personnel security, including material and technical equipment for all fields and forms of health care provided, is clearly anchored by the legislation of the Czech Republic. Without compliance with applicable legislation and conditions, inpatient care in healthcare facilities, outpatient care, or home care cannot be provided.

2.3 Risk Management

Risk management in the healthcare sector focuses on preventing the occurrence of potential unwanted and negative consequences of a situation or event (Terje et al., 2018), which may threaten the functionality of an inpatient medical facility to the extent that the crisis situation deepens.

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A crisis is a situation (OSRI, 2019, p. 48):

> *in which the balance between the basic characteristics of the system (the mission, philosophy, values, goals, and style of functioning of the system) on the one hand and the attitude of the surrounding environment towards the system on the other hand is significantly disturbed.*

Currently, within the Czech Republic, medical facilities are constantly preparing to deal with extraordinary events and crisis situations through risk management activities and the creation of, for example, trauma plans, pandemic plans, or evacuation plans. The two basic concepts of all risk management include "danger" and "risk", when:

- Danger is understood as a source of potential harm.
- Risk is the effect of uncertainty on the achievement of goals.
    - The effect is understood as a deviation from the expected (requested), and in general, it can be not only negative but also positive.
    - The goals can then have different aspects (such as financial, health, and safety goals) and be applied at different levels (such as the strategic level or the level concerning the entire healthcare facility and its processes) (Standard Czech, 2010).

The risk management process according to ISO 31,000 is subsequently composed of two parts, namely, "risk assessment" and "risk treatment" (Danihelka et al., 2014). An extraordinary event is defined as:

> *harmful effects of forces and phenomena caused by human activity and natural influences, as well as accidents that threaten life, health, property, or the environment and require rescue and liquidation work. (The Law on the Integrated Rescue System 2000, 7, p. 3464)*

Extraordinary events, both external risks (which trigger a trauma plan or other action requiring a change in the functioning of the device) and internal risks (leading to device function failure, e.g., fire, power interruption), threaten inpatient medical facilities.

2.4 Population's Perception of Risk

Perceptions of risk and actual risks reveal a mismatch between the scenarios we fear and the ones that are really seriously harmful to us. The perception of risk and real danger are described in the work of Susanna Hertrichová (Bernstein, 2018). According to the illustration, the greatest danger for the population is a terrorist attack or air disaster (Fig. 1). At the same time, the real bigger threats are oncological diseases (Institute of Health Information and Statistics of the Czech Republic, https://www.uzis.cz/index-en.php), traffic accidents, the effects of environmental pollution, and even the impact of an asteroid.

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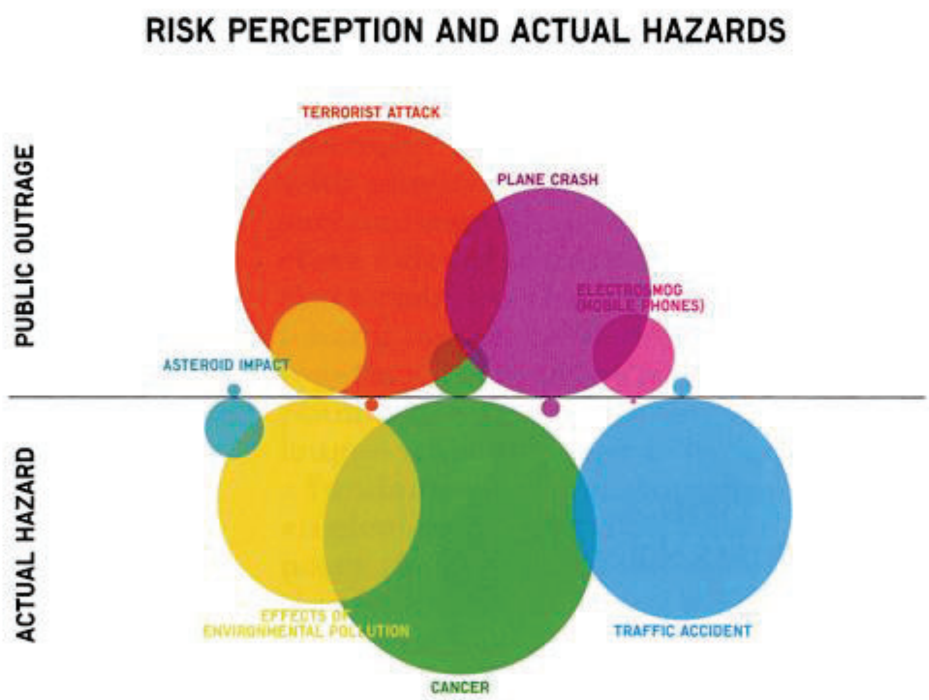

Figure 1. Perception of Risk and Actual Danger (Bernstein, Alison. Risk in Perspective, 2018)

3. VERIFICATION OF THE EFFECTIVENESS OF CRISIS PLANNING IN THE MORAVIAN-SILESIAN REGION

The integrated rescue system in the Czech Republic consists of the basic components, namely the Fire and Rescue Service, volunteer firefighting units, the medical rescue service, and the police. These emergency services are constantly preparing for emergency management, reviewing trauma plans from medical facilities, and conducting tactical exercises. The Health Department of the Moravian-Silesian Regional Authority is involved in the preparation and implementation of these large-scale tactical exercises.

3.1 Participants

The region chose five health facilities to participate in the tactical exercises as contributory organizations. The activity of all participating hospitals within the framework of tactical exercises is the provision and organization of inpatient and outpatient care, namely basic and specialized diagnostic, curative, and preventive care. The total capacity of beds in each hospital was around 450.

3.2 Procedure

As part of the readiness of the integrated rescue system, five tactical exercises took place in the Moravian-Silesian Region in the period 2015–2019, the aim of which was to check the procedures of rescue work in road and railway accidents with many injured people and subsequently the readiness of medical facilities to provide fast, efficient, smooth, and well-organized health care ("launching the Traumatology Plan"). The exercise tested the ability to act and the coordination of the components of the integrated rescue system, as well as the ability of firefighters to provide first aid to injured people and to carry out rescue and rescue work (Figs. 2–4). The aim of the exercise was to practice the method

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of sorting the injured. Among the important results of the exercise was the discovery of a number of possibilities for improvement in the organization of one's intervention and weaknesses, both technical and organizational. At the same time, shortcomings in the field of communication were also revealed.

3.3 Analysis and Results

Evaluation of tactical training and identified shortcomings

In all instances of tactical exercises, poor communication to medical facilities was the obvious cause of the trauma plan's problematic launch and delay. The Regional Operations and Information Center received information about the injured only after the first patients arrived at the medical facility, or the contact point was not informed at all about the launch of the trauma plan. Misinformation also occurred when the number of injured people brought in differed from the reported number and the actual admission to the medical facility, and in one case, the hospital was not informed about the termination of the trauma plan. The interveners who worked at the scene of the accident brought three injured people by themselves in private cars without being informed of the integrated rescue system or moving outside their designated areas in the medical facility, sometimes even complicating the work of the medical personnel. Their cooperation, as well as the cooperation of psychologists in the health sector and security workers who waited a long time for instructions or did not report to the Regional Operations and Information Center, was negatively evaluated. In the case of the first exercise, the telephone connection was overloaded. For other exercises, the medical staff did not report after activation, did not proceed according to the notification decree, but still managed to summon the medical staff after activating the trauma plan within 15 minutes.

Another problematic point was the designation not only of the medical team, including interventions, but also of the material used, which was part and parcel of the integrated rescue system during the initial intervention and was also handed over to the patients during their pre-hospital intervention. This situation resulted in the difficulty of determining the correct records of the used medical material. Among the problems were the lack of reflective vests and, in the first case of tactical training, the medical documentation and administration of the participants in the traffic accident. The masking of the mannequins and their injuries was very authentic, and during the transport there was an inappropriate marking that was insufficiently attached; there was a risk of it being lost during the transport, or the marking was illegible and therefore practically unusable.

The third problematic risk during the activation of the trauma plan included the construction-technical and organizational measures of medical facilities that created problematic areas, the failure to ensure smooth operation of the elevator with the injured, obstacles when handling the injured (e.g., flower pots, inappropriately placed benches, etc.), and very small spaces, for example, for relatives of the disabled.

The medical rescue service evaluated the insufficient marking of positions for the disabled as the most problematic part of the tactical exercise, and the leaders of the intervening functions (e.g., the intervention commander) were insufficiently marked. In two cases, the points of entry to the pre-hospital care station were also insufficiently marked. There was also an inappropriate placement of deceased patients who were close to affected and conscious patients. The shortage was also noted during the intervention in materials such as thermofoil or sorting tapes. In adverse climatic conditions, there is a need to ensure sufficient thermal comfort for patients waiting for triage.

The failure of human factors occurred in the last case, when the dispatcher of the medical operation center of the medical emergency service did not realize the necessity of activating the traumatological plan of the medical facility and constantly verified the diagnoses that would be admitted to the medical facility as part of a tactical exercise. The dispatcher continuously verified the messages and notified the medical facility in advance of the upcoming exercise.

During the tactical exercises, the Fire Rescue Corps negatively assessed the confusing situation of marking which members of the integrated rescue system perform patient triage and its termination, as well as the interchangeability of the colors yellow and green in the first case of the exercise, resulting in non-marking and missing records of medical materials. There was also insufficient marking of the manhole covers, and the marking of the manhole location was made only by a sign on the tunnel wall at a height of about 3 meters. This marking is invisible to firefighters traveling near the ground when the tunnel is smoking.

For the Czech Republic Police, in two cases there were communication breakdowns between the commander of the intervention, the command of the units, cooperation with medical facilities, and their contact persons for providing data for the identification of people in a traffic accident.

Figure 2. Tactical Exercise: Mass Traffic Accident, 2017. (Fire Rescue Service of The Moravian-Silesian Region, 2017)

Figure 3. Tactical Exercise: Collision Between A Bus and An Excavator (Kabarová, Ivana, 2018)

Figure 4. Tactical Exercise: Members of The Integrated Rescue System Triage Patients (Kabarová, I., 2018)

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Figure 5. Tactical Exercise: Train Accident in The Tunnel (Fire Rescue Service of The Moravian-Silesian Region, 2019)

At the same time, the Department of Health, Regional Office of the Moravian-Silesian Region, developed a graphic list of the capacities of providers of acute medical inpatient care based on the experience of tactical exercises and trauma plans of individual health service providers. The list consists of the data of health care facilities in the region that provide both inpatient and one-day care, with an indication of all contact points in individual facilities. The acute inpatient care provider is obliged to set up a contact point in order to ensure the patient's admission and the immediate continuation of the provision of health services. At the same time, there is an obligation to ensure continuous transmission of information on the number of available emergency beds to the contact point, information on restrictions on the provision of urgent care, and cooperation in rescue and liquidation work when dealing with extraordinary events and crisis situations when requested by the provider of emergency medical services (Law on Emergency Medical Services 2011, 6, p. 4841). Furthermore, the data in the table informs about the readiness to treat the injured (e.g., burns, trauma) and the number of immediately allocated beds in the event of an emergency in the Moravian-Silesian Region, with the expansion of the capacity of the bed pool within 2 hours and 24 hours. The data is regularly updated and accessible to members of the crisis teams.

4. CONCLUSION

The exercise tested the efficiency and coordination of the components of the integrated rescue system and the ability of firefighters to provide first aid to affected people and to carry out rescue and recovery work. It revealed the so-called weak points in the activation of the trauma plan. The Department of Health, Regional Office of the Moravian-Silesian Region, within the framework of current and still urgent challenges, constantly supports the electronic sharing of data and communication in the health sector and, at the same time, constantly develops projects to improve the quality and safety of the population for the health care provided in the region in cooperation with the integrated rescue system. The support includes financial subsidies for the integrated rescue system, especially for the ambulance service in the Moravian-Silesian Region. The support focuses on further training of health

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professionals, purchases of ambulances, support for IT systems, and telemedicine, including modernization and strengthening of the resilience of the backbone network of health care providers with regard to potential threats (focusing on acute care—disciplines that are linked to emergency admissions—in order to increase the resilience of the health system). Furthermore, the construction of other urgent incomes, the construction of exit bases and posts, and other important projects in the field of acute and follow-up care

Since November 2018, with the support of the regional authority, the Department of Health, another project, the First Responder System, has been put into operation in the Moravian-Silesian Region, i.e., a system that cooperates between the Moravian-Silesian Medical Rescue Service and volunteer rescuers. First responder is a globally recognized concept of informing and activating trained rescuers in the event of indications of a direct threat to the patient's life. In some cases, registered and trained volunteers can be informed by the operation center about the occurrence of a patient in a life-threatening condition in their vicinity, and the patient can be provided with basic first aid even before the arrival of the medical emergency crew. In conclusion, we also point out that inpatient medical facilities should prepare and rehearse their readiness for all real emergencies that may occur, such as criminal attacks (for example, terrorist attacks, attacks by mentally ill persons, cyber-attacks), interruption of the supply of commodities (energy crisis), migration waves, etc.

5. LIMITATIONS

Another tactical exercise in the Moravian-Silesian region was prepared for the year 2020 to check the trauma plan at the Ostrava University Hospital with the use of highly specialized centers (e.g., the Burn Center). The hospital's bed capacity was around 1,300. Due to other events that hit the Moravian-Silesian region in the period 2020–2022, including COVID-19, the migration wave of refugees from Ukraine, and an emergency that hit the University Hospital in Ostrava at the end of 2019 (the attack of an active shooter), a tactical exercise was held in April 2023. In the same month, another tactical exercise took place with the Integrated Rescue System in a smaller hospital in the Moravian-Silesian Region, the hospital in Blovec.

DEDICATION

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Emergencies, preparedness, and management: a case study of Nigeria

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ABSTRACT

Disasters, whether natural or man-made, have the same effect on society as a whole, causing unwelcome shifts and widespread panic among rescue workers and families who have lost loved ones. The consequences of these panics can only be affected by people's levels of preparedness and their responses to crisis management. The emergency management and preparedness infrastructure in Nigeria is the focus of this paper.

1. INTRODUCTION

Nigeria, like any other country, is subject to a variety of emergencies that necessitate planning and good management. These natural or man-made disasters include the following:

- Natural catastrophes: Nigeria is vulnerable to a variety of natural catastrophes, including floods, droughts, earthquakes, landslides, and extreme weather events such as hurricanes and storms. Flooding is a regular and recurring threat, especially in coastal and flood-prone areas.
- Disease Outbreaks: Like many other countries, Nigeria is vulnerable to disease outbreaks, including epidemics and pandemics. Infectious diseases like cholera, malaria, Lassa fever, and, most recently, the COVID-19 pandemic present substantial problems to public health and emergency management.
- Terrorism and Insurgency: Nigeria has faced terrorism and insurgency, notably in the northeastern region. Boko Haram and other extremist groups' attacks have led in humanitarian crises and population displacement, necessitating emergency response and management.
- Industrial and technological accidents: Nigeria has a diverse range of industries and infrastructure, including as oil and gas facilities, chemical plants, and transportation networks. Pipeline explosions, fires, and chemical spills can all result in situations that demand immediate response and management.
- Civil Unrest and disputes: Communal disputes, political unrest, and civil disturbances can all lead to emergencies that require a coordinated response. Security measures, humanitarian help, and efforts to restore peace and stability are frequently required in these situations.

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2. OBJECTIVE OF THE STUDY

The objective of investigating disaster preparedness and response in Nigeria is to obtain a complete understanding of the country's current state of readiness, identify strengths and shortcomings in existing systems, and suggest improvement measures. The study's goal is to provide a complete assessment of Nigeria's present state of emergency preparedness and response, as well as to offer evidence-based suggestions for strengthening the country's ability to manage catastrophes efficiently and protect lives and infrastructure.

3. EMERGENCIES, PREPAREDNESS AND MANAGEMENT: THE CONCEPTS

3.1 Emergency Management Laws and Policies

In Nigeria, emergency management is primarily governed by the National Emergency Management Agency (NEMA) Act of 1999, which established the National Emergency Management Agency as the legislative authority responsible for disaster and emergency management in the country. The NEMA Act defines the agency's authorities, functions, and organizational structure.

NEMA is responsible for organizing and facilitating disaster management actions throughout Nigeria under the NEMA Act. It works with state emergency management agencies and other stakeholders to plan for, prevent, mitigate, respond to, and recover from disasters and emergencies.

Other laws and policies in Nigeria that support emergency management activities, in addition to the NEMA Act, include:

- The Civil Defense legislation: This legislation created the Nigeria Security and Civil Defense Corps (NSCDC), which aids in disaster management, particularly in the areas of civil defense and key national infrastructure protection.
- The Fire Service Act: This act establishes and regulates fire departments in Nigeria. It defines the roles of fire departments in responding to fires and other situations involving hazardous chemicals.
- The Quarantine statute: This statute gives the Federal Ministry of Health the authority to take steps to prevent the introduction and spread of contagious illnesses in Nigeria. It establishes a legislative framework for dealing with public health crises and outbreaks.
- The Environmental Impact Assessment (EIA) Act: While not specifically aimed for crises, the EIA Act mandates project developers to conduct environmental effect assessments before engaging in certain operations. This aids in the identification of potential risks and the implementation of appropriate risk mitigation strategies.
- State-level laws and policies: To supplement the national framework, certain Nigerian states have implemented their own emergency management laws and policies. The scope and content of these laws may differ between states.

It is worth noting that, as a federal republic, Nigeria has a decentralized emergency management system. While NEMA serves as a national coordinator, state emergency management agencies are responsible for emergency management actions within their respective states.

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3.2 Entities involved in emergency preparedness and response

Emergency preparedness and response in Nigeria require the coordination and collaboration of multiple entities at the national, state, and local levels. These organizations perform distinct roles in the preparation, execution, and management of emergency operations. The following are the important entities in Nigeria involved in emergency preparedness and response:

- National Emergency Management Agency (NEMA): NEMA is the key agency in charge of national emergency management. Its mission is to coordinate and supervise disaster management activities such as preparedness, response, and recovery. To guarantee successful emergency response, NEMA works with other government agencies, non-governmental organizations, and foreign partners.
- State Emergency Management Agencies (SEMAs): In Nigeria, each state has its own State Emergency Management Agency in charge of emergency preparedness and response within their respective domains. SEMAs collaborate closely with NEMA and other relevant stakeholders to establish state-specific emergency response plans, coordinate resources, and put disaster management strategies into action.
- Local Government Emergency Management Committees (LGEMCs): These committees are formed at the local level to help with emergency planning and response operations. To achieve efficient emergency management within their territories, LGEMCs collaborate with SEMAs, community leaders, and local stakeholders.
- Nigerian Security and Civil Defense Corps (NSCDC): The NSCDC is critical in emergency response, particularly in security and civil protection crises. During an emergency, they provide security, crowd control, and support in maintaining law and order.
- Nigerian Police Force (NPF): The Nigerian Police Force is responsible for emergency response, law enforcement, and public safety during emergencies. They collaborate with other agencies to keep security and order in affected areas.
- The Nigerian Armed Forces, which include the Nigerian Army, Navy, and Air Force, are active in emergency response, notably in cases of terrorism, insurgency, and civil disturbance. They help to maintain security, execute rescue operations, and supply humanitarian supplies in disaster-stricken areas.
- Health and Medical Services: The Federal Ministry of Health, state health ministries, and healthcare facilities, among others, play critical roles in emergency response, notably in disease epidemics and public health emergencies. During an emergency, they provide medical help, disease surveillance, vaccination programs, and other healthcare services.
- Non-Governmental groups (NGOs) and Humanitarian Organizations: A number of NGOs and humanitarian groups operate in Nigeria, assisting with emergency planning and response. These organizations play an important role in delivering humanitarian aid, carrying out relief activities, and assisting affected communities.
- International Organizations and Donors: During emergencies, international organizations such as the United Nations, World Health Organization (WHO), International Red Cross and Red Crescent Movement, and numerous donor agencies contribute assistance, knowledge, and resources to Nigeria. They help with capacity building, resource mobilization, and coordination.

Effective emergency response and preparedness necessitate strong cooperation and collaboration across these agencies. They collaborate to ensure that emergency responses are well-coordinated, prompt, and efficient, thereby saving lives and reducing the impact on affected populations.

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3.3 Phases of Emergency Preparedness and Management

In Nigeria, emergency preparedness and management often take a multi-stage strategy with numerous stages. While nomenclature and classification may differ, the following are the frequently recognized phases of emergency preparedness and management:

- Prevention/Mitigation: This phase focuses on initiatives that try to prevent or mitigate the effects of disasters. It entails detecting potential hazards, assessing risks, putting mitigation measures in place, and increasing resilience in communities and key infrastructure. Land-use planning, construction standards, environmental protection, public awareness campaigns, and education initiatives are examples of mitigating strategies.
- Preparedness: The phase of preparation entails creating strategies, procedures, and resources to successfully respond to calamities. It entails tasks including developing disaster response plans, training and drills for emergency personnel, establishing communication systems, stockpiling necessary equipment and supplies, and coordinating with important parties. Preparedness programs attempt to improve reaction skills and provide a quick and coordinated response in the event of an emergency.
- Response: The initial activities done to address the effects of an emergency or disaster are referred to as the response phase. Its primary goals are to save lives, protect property, and stabilize the situation. Emergency evacuations, search and rescue operations, medical help, building up temporary shelters, delivering emergency supplies, establishing emergency operations centers, and coordinating the response efforts of multiple agencies and groups are examples of response activities.
- Recovery: After the urgent response activities are completed, the recovery phase begins. It entails attempts to reconstruct and repair damaged communities, infrastructure, and services. Debris removal, infrastructure repairs, psychological care for impacted individuals, community rehabilitation, economic recovery, and long-term planning to prevent repeat disasters are all examples of recovery operations. The goal is to return impacted areas to pre-disaster conditions or to increase resilience to future occurrences.
- Risk reduction and preparedness improvement: This phase entails analyzing the lessons learned from the emergency response and recovery operations and putting that knowledge to use in updating and improving mitigation and preparedness strategies. Implementing risk-reduction measures, upgrading response plans and systems, updating training programs, and incorporating new technology and best practices into emergency management processes are all part of it.

It is vital to notice that these phases are intertwined and frequently overlap. To create resilience and lessen the impact of future catastrophes, effective emergency management necessitates a continuous cycle of readiness, response, recovery, and mitigation.

In Nigeria, the National Emergency Management Agency (NEMA) is critical in coordinating and enabling various phases of national emergency preparedness and management. State emergency management agencies, local governments, and other stakeholders all help to implement these phases within their jurisdictions.

3.4 Long-Term Resources for Disaster Planning and Management

Long-term disaster planning and management resources in Nigeria include a variety of techniques, tools, and projects targeted at increasing resilience, readiness, and response capabilities. Here are some significant resources for long-term catastrophe preparation and management in Nigeria:

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- National Emergency Management Agency (NEMA): NEMA is Nigeria's major disaster management agency. It provides catastrophe risk reduction resources and skills, as well as emergency preparedness, response, and recovery. NEMA collaborates closely with state emergency management agencies to coordinate national and local actions.
- National Disaster Management Framework: Nigeria has created a National Disaster Management Framework including policies, plans, and activities for disaster risk reduction, emergency response, and recovery. This framework acts as a guide for all disaster management stakeholders and serves as a foundation for long-term planning.
- Risk Assessment and Mapping: Conducting risk assessments and mapping is critical for understanding Nigeria's vulnerability and exposure to various hazards. These assessments aid in identifying high-risk locations, demographics, vital infrastructure, and assets, allowing for improved resource planning and allocation.
- Early Warning Systems: Nigeria has worked to build and improve early warning systems in order to offer timely alerts and information about approaching disasters. These systems aid in proactive decision-making, evacuation planning, and catastrophe mitigation.
- Capacity Development and Training: Long-term catastrophe planning and management necessitate the use of a competent and knowledgeable personnel. Nigeria has engaged in capacity-building and training initiatives to improve the capacities of emergency responders, government officials, and community members. These programs concentrate on topics including risk assessment, emergency response, incident command systems, and community resilience.
- Emergency Management Legislation and Policies: As previously stated, Nigeria has emergency management legislation and policies. These legislative frameworks serve as the foundation for catastrophe planning, risk mitigation, and response efforts.
- International Assistance and Partnerships: Nigeria receives assistance from international organizations such as the United Nations, the World Bank, and regional organizations such as the Economic Community of West African States (ECOWAS). Through finance, technical help, and knowledge sharing, these collaborations contribute to long-term resources for disaster planning and management.
- Research and Data Collection: In Nigeria, research institutes and agencies conduct studies and gather data on many aspects of disaster management. These activities contribute to better knowledge, the development of evidence-based policies, and the implementation of effective initiatives.

It is crucial to note that the resources available for disaster planning and management may differ among Nigeria's states. Local governments and communities are also critical in formulating and implementing long-term strategies to address unique hazards and difficulties in their community.

3.5 Emergency Planning and Management Challenges

In Nigeria, emergency planning and management encounter a number of problems that might have an impact on the effectiveness of response activities. Among these difficulties are:

- Limited Resources: Inadequate money, insufficient infrastructure, and a scarcity of equipment and supplies can all impede emergency planning and management. The inability to design solid response plans, train staff, obtain appropriate equipment, and maintain emergency infrastructure is frequently hampered by a lack of financial resources.

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- Weak Institutional Capacity: Government entities, especially emergency management organizations, may have limited capacity to effectively coordinate and respond to emergencies. Inadequate training, limited staffing, obsolete procedures, and insufficient interagency collaboration can all contribute to this. Building institutional capacity is critical for effective emergency management.
- Communication and Information Sharing: During an emergency, timely and effective communication is crucial. However, communication infrastructure and information sharing issues might stymie coordinating attempts. Inadequate communication networks, particularly in rural places, can stymie the dissemination of critical information and coordination among emergency agencies.
- Urbanization and Population Density: Nigeria's rapid urbanization has resulted in increasing population density in cities, making them more vulnerable to disasters. The concentration of people and infrastructure in metropolitan settings creates obstacles for evacuation, emergency shelter, and the supply of key services during emergencies.
- Security Concerns: Nigeria experiences security issues such as terrorism, insurgency, and communal disputes, which can make emergency planning and response operations more difficult. These security concerns may restrict access to damaged areas, stymie relief efforts, and endanger emergency responders and affected communities.
- Climate Change and Environmental Degradation: Nigeria is vulnerable to a variety of climate-related hazards, including floods, droughts, and desertification. Climate change worsens these problems by increasing the frequency and severity of extreme weather occurrences. Environmental degradation, such as deforestation and erosion, increases catastrophe susceptibility.
- Community Engagement and understanding: Ineffective emergency management can be hampered by a lack of community engagement and understanding regarding disaster planning and response procedures. Promoting community engagement, informing the public about hazards, and fostering community-based projects are critical to increasing resilience and decreasing vulnerability.
- Political and administrative considerations: Political instability, bureaucratic processes, and inefficiencies in administration can all have an impact on disaster preparedness and response operations. Administration changes or a lack of political commitment to prioritize disaster management can undermine continuity and hamper effective coordination.

Addressing these issues would necessitate a multifaceted approach that includes increased finance and resource allocation, capacity building, improved communication systems, community involvement, and incorporating disaster risk reduction into development planning. Strengthening legal and institutional frameworks, boosting research and data gathering, and cultivating relationships with national and international stakeholders are also critical for overcoming these obstacles.

Nigeria must constantly analyze and address these difficulties in order to improve emergency planning and management capabilities and successfully respond to disasters and emergencies.

4. DISCUSSION AND RECOMMENDATIONS

In Nigeria, emergency preparedness is a major component of disaster management. Given the country's vulnerability to numerous hazards such as natural disasters, disease outbreaks, terrorism, and civil unrest, it is critical to have effective emergency preparedness mechanisms in place to reduce the impact of calamities and protect lives and infrastructure.

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Several critical factors are required for effective emergency preparedness:

- Risk Assessment: Conducting comprehensive risk assessments aids in identifying and comprehending the dangers and vulnerabilities unique to Nigeria's various areas. This data informs the formulation of tailored preparedness programs and aids in the prioritization of resources and actions.
- Early Warning Systems: It is critical to establish and strengthen early warning systems in order to alert the public and relevant authorities about imminent emergencies in a timely manner. To deliver alerts and advisories, these systems rely on reliable monitoring, data processing, and communication networks, enabling proactive preparedness and response activities.
- Emergency Planning: It is critical to develop complete emergency response plans and practices. These plans define the roles and duties of numerous agencies and stakeholders, as well as coordination methods, communication protocols, and standard operating procedures for a variety of emergencies. To ensure their effectiveness, the plans should be evaluated, modified, and tested on a regular basis through exercises and drills.
- Training and Capacity Building: It is critical to build the capacity of emergency management employees, first responders, and other important stakeholders through training programs. Incident command systems, disaster response protocols, search and rescue techniques, medical triage, and public information management should all be covered in training. Continuous training and skill development ensure that the workforce is competent and well-prepared.
- Public Awareness and Education: It is critical to educate the public on potential risks, preparedness measures, and suitable response activities. Public awareness campaigns, community exercises, and the distribution of instructional materials all contribute to fostering a culture of readiness and empowering citizens to behave appropriately during emergencies.
- Interagency cooperation: Efficient disaster response requires effective cooperation among multiple government agencies, non-governmental organizations, and community groups. During an emergency, clear communication channels, coordination procedures, and information-sharing platforms promote collaborative decision-making and resource allocation.
- Infrastructure and Logistics: It is crucial for efficient disaster response to ensure the availability and functionality of critical infrastructure, such as communication systems, transportation networks, emergency shelters, and healthcare facilities. To satisfy the demands of affected populations, adequate logistical support, such as storing emergency supplies, equipment, and medical resources, is required.
- International Cooperation: Increasing Nigeria's emergency readiness through international cooperation, information sharing, and partnerships with neighboring countries, regional authorities, and international organizations. During an emergency, collaboration enables for resource mobilization, the exchange of best practices, and access to expertise and assistance.

Regular examination and modification of preparedness plans, learning from previous catastrophes, and incorporating new technology and best practices are critical for sustaining and improving Nigeria's emergency preparedness. Continuous efforts in this area help to increase resilience, reduce risks, and mitigate the impact of disasters on communities and infrastructure.

5. CONCLUSION AND RECOMMENDATIONS

Because of the country's vulnerability to numerous risks, emergency preparedness and response are critical in Nigeria. A multifaceted approach is required, integrating government agencies, community organizations, and foreign partners. Nigeria should prioritize the following in order to improve emergency preparedness and response:

- Improving coordination and collaboration: It is critical to strengthen coordination mechanisms between national, state, and local institutions. A well-coordinated reaction requires effective communication, information exchange, and collaborative planning.
- Capacity building and training: It is critical to invest in training programs and capacity building initiatives for disaster management officials, first responders, and members of the community. This ensures that people have the skills and information they need to respond effectively in an emergency.
- Public awareness and education: It is vital to raise public knowledge and education regarding potential risks, preparedness measures, and reaction actions. Encouraging communities to play an active role in disaster preparedness can result in a more resilient and self-sufficient population.
- Infrastructure and resource investment: Adequate infrastructure, such as communication systems, transportation networks, and emergency response facilities, is critical for efficient emergency response. To satisfy the demands of affected populations, adequate resources for emergency supplies, equipment, and medical resources must be allocated.
- Integrating disaster risk reduction measures into development planning at all levels: Integrating disaster risk reduction measures into development planning at all levels can assist reduce vulnerabilities and improve resilience. This includes land-use planning, construction code enforcement, and promoting environmentally friendly practices.
- Continuous evaluation and improvement: It is critical to evaluate emergency response plans on a regular basis, conduct post-incident assessments, and incorporate lessons learned into future preparedness activities. This guarantees that emergency management plans are both adaptable and effective.
- International cooperation: Participating in international cooperation, exchanging best practices, and gaining access to resources and experience from international partners all help Nigeria's emergency preparedness and response capabilities.

Nigeria should increase its ability to effectively prepare for and respond to emergencies, alleviate the impact on impacted communities, and promote resilience in the face of future dangers by prioritizing these factors.

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The integration of behavior-based safety (BBS) as a company value is advocated!

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KEYWORDS

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ABSTRACT

Nearly all cases involving dangerous substances involve human error. Human error caused several disasters, including Bhopal and Chernobyl. The Health and Safety Executive (2023) states that human error management must be as rigorous as technical and engineering processes to prevent accidents and diseases. Human factors—positive or negative—influence employee behavior in a firm. Positive variables can improve safety culture, while reactive variables can hurt it. Restoring a strong safety culture depends on how top executives handle safety problems. A comprehensive safety culture framework integrates information from many conceptualizations to show how safety culture evolves and what variables influence it. This article summarizes qualitative or informal organizational behavior-based safety (BBS) deployment.

1. INTRODUCTION

An analysis of incidents and accidents indicates that human error is a contributing factor in nearly all instances involving exposure to hazardous substances. The primary factor behind numerous catastrophic incidents, such as those that occurred at Bhopal and Chernobyl, was attributed to human error. According to the Health and Safety Executive (2023), the efficacy of human error or mistake management is contingent upon its robustness being on par with the technical and engineering protocols implemented to avert accidents and illnesses. Human factors, whether negative or positive, refer to the elements within an organizational setting that impact the attitudes and conduct of employees. Positive variables have the potential to enhance the safety culture, whereas reactive variables may have a detrimental effect on it.

Lal (2023) posits that various factors such as limited time, fear, and inadequate resources can contribute to a mindset where safety decisions are not prioritized, safety culture is downplayed, and accidents gradually accrue, resulting in detrimental effects on individuals and assets. The response of top-level executives to safety-related incidents is considered a crucial determinant in reinstating a robust safety culture. Health, Safety, and Environment (HSE) experts emphasize the significance of

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maintaining equilibrium between challenges and concerns when incorporating behavior-based safety (BBS) and promoting a sound safety ethos.

2. BACKGROUND

BBS is a proactive method for encouraging safe behavior in a specific area. BBS is concerned with lowering dangers, risks, and events by observing a person's behavior and identifying what happens when that behavior occurs. It entails assessing the implications of a certain behavior and providing appropriate reinforcement for the desired behavior. BBS is dependent on total trust and collaboration between managers and employees. BBS is significant because it provides long-term solutions for risk and hazard elimination. This life-saving method promotes a safety culture in the workplace, which is critical for long-term success. According to the Health and Safety Authority (HSA), organizations strive to build a holistic safety culture within their area of responsibility. This is accomplished when each employee regards safety as a value and ensures the safety of coworkers. The BBS strategy is all about reducing risky behaviors and continuously improving safety performance (Safety Culture, 2023).

The micro-BBS strategy seeks to modify employee behavior in order to increase workplace safety. The behavioral safety procedure comprises the following seven steps:

- An identification of potentially problematic behaviors, such as hazardous or risky ones.
- A determination of the underlying causes of the observed behaviors.
- A creation of potential corrective measures.
- An assessment of corrective measures.
- A creation of the processes required to execute the BBS program.
- An execution of the BBS program.
- An evaluation of the BBS program's collected data to determine if it addressed the problem or increased safe behavior.

The macro-BBS approach seeks to effect lasting cultural change within an organization. This is the culture of safety that the majority of organizations strive to accomplish through their safety programs. Michael Topf designed a six-step procedure for achieving this long-term workplace safety solution. The six stages are as follows:

- Assess and analyze the workplace culture.
- Teach and instruct every employee about behavior-based workplace safety.
- Encourage the participation of all employees in the BBS program.
- Strengthen consciousness, accountability, self-observation, and self-management.
- Continuously support and dedicate oneself to employees.
- Provide evaluation and feedback.

Three factors—internal personal factors, external environmental factors, and behavior factors—reflect a complete safety culture, according to Geller (Safety Culture, 2023). These conditions must exist at all times. The integrated approach is fundamental to BBS and is founded on Geller's seven principles. This integrated approach employs both individual and organizational behavior to achieve a culture of total safety. Here are the seven principles:

- The behavior modification techniques should be observable.
- External factors that can aid in the comprehension and improvement of behavior should be determined.

- Antecedents should be utilized to direct behavior, whereas consequences should be utilized to motivate behavior.
- Positive outcomes to reinforce desirable conduct should be highlighted.
- An objective and measurable BBS program should be ensured.
- Hypotheses and combined BBS program data should be generated, in order not to limit the possibilities.
- A BBS program that takes into account the emotions and attitudes of employees should be created.

3. COMPONENTS OF THE BBS PROGRAM

The essential components of a BBS program for effective implementation are as follows (Safety Culture, 2023):

- **Standards for conduct and performance**, including the vision, mission, priorities, policies, processes, and methods, as well as everything else involved, must be communicated to all program participants.
- **Physical resources,** which consist of the tools, equipment, funds, and facilities that are required to implement a BBS system, while psychosocial resources include time, training, culture, and leadership.
- **A system of measurement** that ensures that behavioral observations are quantifiable by establishing criteria for evaluating performances and providing objective feedback.
- **Effective consequences** that can increase positive behavior. Positive reinforcements are one type of effective consequences.
- **Appropriate application**: The system must be equitable; in other words, it provides recognition and rewards when appropriate.
- **A continuous evaluation of the BBS program** enables the program to be continuously enhanced; this will also determine the effectiveness of the program.

The interdependence of work and safety implies that establishing and maintaining a safety culture requires a deliberate attention to multiple levels of impact on employee safety and welfare. Integrated interventions that are effective exhibit key attributes such as the development of interventions, their implementation, and the resultant outcomes.

4. ADVANTAGES AND DISADVANTAGES OF THE BBS PROGRAM

The following are some pros and cons of a BBS approach (Gould, 2019):

Pros:

- BBS programs encourage employee participation. BBS is advantageous in that it encourages the participation of all employees. The program attempts to provide a clear picture of what is working and what is not in terms of safety. In fact, a genuine BBS program cannot function without the participation and involvement of all employee levels.
- BBS programs utilize positive reinforcement. Regarding workplace safety, a small amount of optimism can go a long way. Workplace "safety" is not everyone's favorite topic. The majority of employees detest training sessions and safety meetings. Putting a positive spin on safety can enhance the workplace's overall safety culture.

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Cons:

- BBS programs are challenging to maintain. To be effective, a BBS program requires the complete support of senior management. It must also be utilized and evaluated frequently. BBS will be ineffective if it is merely "implemented" without structure, commitment, and follow-up.
- Inadvertently, BBS programs assign "blame" to employees. Although assigning "blame" to employees is not the goal of a genuine BBS program, it is difficult to isolate its effects. After all, BBS is intended to emphasize individual actions and behaviors.
- BBS programs can lead to erroneous reporting. Due to the structure of the program, which rewards "good" conduct, accidents and injuries may go unreported. Nobody desires to be the one to end the "days without injury". When things go awry or unsafe behavior is observed, employees are also averse to investigations and in-depth conversations.
- BBS programs frequently identify the incorrect "root cause". BBS necessitates incident investigations when unsafe behaviors are observed or injuries occur. But frequently, these investigations focus on what occurred rather than the underlying cause or why it occurred.

5. BBS: IMPORTANT CONSIDERATIONS

BBS is not something that can be gradually implemented. Effective implementation requires meticulous planning, long-term commitment, and organization-wide support. How should one then proceed?

According to EHS Today, the six most common errors made by businesses when implementing a BBS program entail the following (Gould, 2019):

- Believing that participation and observation are the foundations of BBS.
- Failing to utilize positive reinforcement effectively and systematically.
- Only changing hourly employees.
- Making safety based on employee behavior the principal responsibility of employees.
- Not training managers, administrators, and hourly workers on the fundamental principles of behavior-change technology.
- Attempting to implement an activity-based "program" within the organization.

6. OBSTACLES THAT EMPEDE BBS EFFECTIVENESS

The development of a safety culture progresses from fundamental principles to fundamental values through the dedication of top-level management, ultimately leading to the realization of the advantages of BBS. Many businesses engage in thorough preparation of safety culture interventions, yet struggle to sustain them as enduring modifications due to insufficient attention to organizational variables. The issues identified by Lal (2023) include managers who persist in adhering to a culture of dependence on safety, a lack of motivation among lower-level workers to engage in mentally stimulating activities, insufficient support from relevant heads of departments and managers, and inadequate capacity to mobilize and engage all employees and associates.

To promote safe practices, it is recommended to implement measures such as modifying behavior, establishing structured infrastructure, monitoring and enforcing safety protocols, providing training and education, and utilizing positive and negative reinforcement techniques. Efficient implementation of safety measures can be achieved when it is considered a line-of-duty responsibility and integrated into daily activities. During regular meetings, it is recommended that the management team engage in discussions pertaining to safety metrics in addition to other operational parameters. The successful execution of any project necessitates the unwavering commitment and active participation of top-level management. In the absence of such involvement, the desired outcomes of such projects may not be realized (CPCL, 2021).

In order to establish a safe work environment, it is imperative to cultivate a fundamental need for safety practices, including the utilization of personal protective equipment (PPE) by all personnel, from the highest level of management to the lowest level of employees. It is essential that all individuals are cognizant of the safety policy and that top management is actively involved in all safety-related activities. Training is a crucial component in developing a safety culture, and it is recommended that at least 3% of man-hours be allocated to employee training.

The commitment of top management is an essential prerequisite for any action to be taken. The implementation of monitoring as a boardroom practice requires a dedicated commitment from management. The sustainability of a positive safety culture is contingent upon its integration into the boardroom and the level of discourse it receives therein. The efficacy of the system is contingent upon its integration into habitual behavior, which must be sustained over an extended period to effect lasting change. The reason for its failure can be attributed to the absence of a clear corporate vision or policy (Kaila, 2022, and 2022a).

One of the reasons businesses fail to maintain a positive safety culture is attributed to human error or organizational politics; this is often due to underlying conflicts and collective faults within the organization, which can impede the implementation of effective safety measures. BBS aims to address and resolve organizational concerns in tandem, with the goal of cultivating a positive work environment. The acquisition of knowledge and skills by employees through training is contingent upon their active engagement in the learning process, assimilation of information, and practical application of the acquired knowledge. According to Tata Steel (2021), achieving success in safety culture is not a static objective, but rather a dynamic process characterized by fluctuations and variations.

7. CONCLUSION AND RECOMMENDATIONS

Due to the challenges associated with long-term commitment, many businesses perceive the adoption of safety measures as a means of preserving their reputation. Consequently, they execute their assigned tasks and subsequently adopt a passive stance, anticipating unforeseen incidents. Certain enterprises have initiated a safety culture intervention but failed to follow through due to their predominant focus on individual behaviors rather than organizational behaviors. The exchange of ideas and perspectives at various levels within an organization pertaining to topics such as incentives, interpersonal connections, attitudes, and obstacles is believed to generate a novel model of organizational conduct, commonly known as BBS. BBS has evolved from a narrow emphasis on injury reduction (which, regrettably, involves victim blaming) to a comprehensive approach that considers not only behaviors but also the work environment, cultural factors, systems, and employee attitudes; this approach aims to enhance organizational cultures, values, and performance (Johnson, 2021).

The development of a favorable safety culture is a gradual process that necessitates ongoing scrutiny of its sustainability over an extended period. According to Wong et al. (2021), in order to effectively promote a culture of safety and encourage individuals to prioritize it, it is essential for management to consistently evaluate and analyze their strategies while implementing diverse interventions. ISO 45001:2018 (SEIL, 2023) stipulates that risk assessment should encompass human competence and behavioral factors, which should be regarded as internal concerns for risk management.

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BBS implementation in the workplace involves careful planning, participation, and commitment from all levels of the business. Here are a few suggestions for a smooth implementation:

- **Leadership Commitment**: Obtain senior management's commitment to prioritizing and supporting BBS efforts. Leaders must establish a clear vision for safety, allocate the required resources, and actively participate in BBS activities.
- **Employee Involvement**: Ensure that employees at all levels are involved in the BBS process. Seek their feedback, invite them to join safety committees or teams, and empower them to take responsibility for safety projects.
- **Training and Education**: Educate employees on BBS principles, safe work practices, danger identification, and the importance of their conduct in maintaining a safe workplace. Refresher courses and continuous education should be used to reinforce this training on a regular basis.
- **Observation and Feedback**: Create a method for observing and recording employee behaviors. Supervisors and designated observers should be trained to perform non-punitive observations, provide constructive criticism, and accurately document observations. Maintain confidentiality while emphasizing the importance of observations as a tool for progress.
- **Conduct Analysis**: Examine the collected data for trends, patterns, and the underlying causes of risky conduct. Utilize this data to prioritize specific behaviors for change and create tailored interventions.
- **Metrics and Goal Setting**: Establish measurable targets for corporate and individual safety performance. Define key performance indicators (KPIs) to monitor progress and assess the effectiveness of BBS activities. Employees should be kept up to date on progress, and milestones should be celebrated on a regular basis.
- **Reinforcement and Recognition**: Use a positive reinforcement system to identify and reward safe actions. To promote safe behaviors and encourage employees to participate actively, use a combination of verbal recognition, incentives, awards, and public gratitude.
- **Constant review and Improvement**: BBS is a continual process that necessitates continuing review and improvement. Review the efficacy of BBS initiatives on a regular basis, elicit employee input, and make appropriate program improvements.
- **Safety Culture Integration**: BBS should be integrated into the organization's broader safety culture. Align BBS with existing safety initiatives, rules and procedures, and foster a culture of shared responsibility for safety.
- **Communication and Engagement**: Create effective communication channels to keep employees up to date on BBS operations, progress, and results. Encourage open communication, create chances for input, and include employees in safety decision-making processes.

By many accounts, successful BBS installation takes time, effort, and a commitment to ongoing improvement. To accomplish long-term improvements in workplace safety, a supportive organizational culture, active employee participation, and continued leadership involvement are required.

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Driving Safety Innovation: The Nexus of STEM Education and Road/Traffic Safety

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KEYWORDS

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ABSTRACT

The convergence of STEM (Science, Technology, Engineering, and Mathematics) education and road/traffic safety represents a pivotal nexus of innovation, education, and collaboration. This paper explores the multifaceted relationship between STEM and road safety, highlighting its profound impact on the present and its potential to shape a safer future. STEM's role in road safety innovation encompasses the development of advanced vehicle technologies, smart infrastructure, and data-driven solutions. Moreover, STEM education contributes to heightened awareness through curriculum integration, interactive tools, and community outreach. Collaboration between STEM experts and road safety professionals yields holistic strategies, propelling the evolution of transportation safety. While challenges of accessibility, ethics, and technological adaptation persist, their proactive resolution is paramount for unleashing the full potential of STEM education in enhancing road safety. In conclusion, the symbiotic synergy between STEM education and road/traffic safety is not only a testament to human ingenuity but also a catalyst for safer roads and sustainable transportation systems.

1. INTRODUCTION

The modern world is characterized by rapid technological advancements and a growing emphasis on safety and sustainability. At the heart of this transformation lies STEM education – an interdisciplinary approach that integrates Science, Technology, Engineering, and Mathematics to solve complex problems and innovate for the future. Concurrently, road and traffic safety have become critical concerns due to the escalating challenges posed by urbanization, increasing vehicle populations, and changing transportation landscapes. The intersection of STEM education and road/traffic safety signifies a dynamic relationship that holds immense potential for shaping safer, more efficient, and sustainable transportation systems (Love, 2013; Love, 2015; Kelley et al., 2016; Johnson, 2018; KROS, 2019; Love, 2019; Crowe, 2021; Peters-Burton, 2021; Kelley et al., 2023; Love, 2023).

STEM education transcends traditional educational boundaries, encouraging students to approach real-world challenges from a holistic, multidisciplinary perspective. It equips learners with the analytical, critical thinking, and problem-solving skills necessary to tackle complex issues. Science forms the foundation for understanding the world around us, while Technology provides the tools to harness this

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knowledge. Engineering applies scientific principles to design solutions, and Mathematics serves as the language of quantification and pattern recognition. The synergy of these disciplines fosters innovation and drives progress in various domains (Bryan, 2015; Johnson, 2021).

In an era marked by urbanization, globalization, and increased mobility, road and traffic safety have become paramount concerns. Traffic accidents result in substantial loss of life, injuries, economic burden, and environmental impact. As cities expand and transportation networks become more intricate, addressing road safety has become a pressing challenge for policymakers, engineers, and citizens alike. The consequences of accidents extend beyond immediate casualties, affecting families, communities, and the broader societal fabric. Consequently, the need to prevent accidents and enhance road safety has sparked innovative efforts across industries. The dynamic relationship between STEM education and road/traffic safety holds immense potential for creating safer transportation systems. Through innovative solutions and heightened awareness, STEM education contributes to the reduction of accidents and the optimization of transportation infrastructure. This synergy not only enriches STEM education with real-world context but also empowers societies to confront one of the most significant challenges of our time – ensuring the safety of individuals and communities on roadways (Love et al., 2020; Love et al., 2022; Love, 2023; Dalal et al., 2023; Love et al., 2023).

In the following sections, 2 to 6, we will delve deeper into the various facets of this relationship, exploring how STEM education influences road safety innovation and enhances public awareness (Love, 2013; Bryan et al., 2015; Love, 2015; Kelley et al., 2016; Johnson et al., 2018; KROS, 2019; Love, 2019; Bautista-Montesano et al., 2020; Love et al., 2020; Bautista-Montesano et al., 2021; Crowe, 2021; Peters-Burton et al., 2021; Qorbani et al., 2021; Siripatana et al., 2021; Wang et al., 2021; Love et al., 2022; Dalal et al., 2023; Kelly et al., 2023; Love, 2023; Love et al., 2023). The information presented hereafter is illustrative and by no means exhaustive, but it covers the main areas.

2. STEM EDUCATION'S ROLE IN ROAD/TRAFFIC SAFETY INNOVATION

2.1 Engineering and Design

- **Development of Advanced Vehicle Safety Technologies**: STEM-educated engineers play a pivotal role in creating cutting-edge safety technologies for vehicles. This includes innovations like collision avoidance systems, automatic emergency braking, lane departure warnings, and adaptive cruise control. These technologies are designed to mitigate human errors, a significant contributor to accidents.
- **Designing Road Infrastructure for Improved Safety**: STEM professionals contribute to the design of safer road infrastructure. They create innovative road layouts, incorporate features like roundabouts that reduce collision points, and design pedestrian-friendly crossings. These designs aim to enhance both vehicle and pedestrian safety.

2.2 Technology and Software

- **Simulation Software for Testing Road Safety Scenarios**: STEM experts develop sophisticated simulation software that models various road safety scenarios. This allows engineers and policymakers to test potential changes in road design, traffic management strategies, and vehicle interactions in a controlled digital environment before implementing them in the real world.

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- **Traffic Management Systems for Efficient Traffic Flow**: STEM-educated technologists design and implement traffic management systems that use real-time data to optimize traffic flow. These systems can adjust traffic signal timings, manage lane usage, and even suggest alternate routes to prevent congestion, thereby reducing accident-prone situations.

2.3 Data Analysis and Research

- **Utilizing Big Data for Identifying Accident Patterns**: STEM professionals leverage big data analytics to identify patterns in accidents, near-misses, and risky behaviors. By analyzing this data, they can pinpoint high-risk areas, road conditions, and driver behaviors that contribute to accidents, leading to targeted interventions.
- **Predictive Analytics for Proactive Safety Measures**: STEM-educated analysts use predictive modeling to forecast potential accident hotspots based on historical data and current trends. This enables authorities to implement proactive safety measures such as increased signage, road repairs, and increased law enforcement presence.

The integration of STEM principles into road and traffic safety innovation is not only about technological advancements, but also about applying scientific principles to address real-world challenges. A comprehensive understanding of physics, mathematics, and engineering principles enables professionals to develop solutions that can reduce the frequency and severity of accidents, ultimately saving lives and resources. As technology continues to evolve, the role of STEM education in road safety innovation becomes increasingly critical in shaping safer transportation systems for the future.

3. EDUCATION AND AWARENESS THROUGH STEM

3.1 Curriculum Integration

- **Incorporating Road Safety Topics into STEM Education**: STEM curricula can be enriched by integrating road safety concepts. By introducing students to the physics of collisions, vehicle dynamics, and the mechanics of safety systems, educators can foster a deeper understanding of the science behind road safety measures.
- **Teaching the Mathematics of Risk Assessment**: STEM education equips students with the mathematical tools needed to assess risk. They can analyze accident data, calculate the probabilities of collisions, and model the effects of safety interventions. This quantitative approach enhances their ability to design effective safety measures.

3.2 Interactive Learning Tools

- **Virtual Reality Simulations of Road Safety Scenarios**: Through virtual reality (VR) simulations, students can experience and understand dangerous traffic scenarios without actual risk. This immersive learning approach helps them grasp the consequences of unsafe behavior and appreciate the importance of road safety measures.
- **Coding Projects Related to Traffic Management**: Encouraging students to develop coding projects related to traffic management systems allows them to explore real-world solutions. This hands-on experience enhances their technological skills while exposing them to the complexities of managing traffic for safety and efficiency.

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3.3 Outreach Programs

- **STEM-Focused Road Safety Workshops**: Organizing workshops that combine STEM education with road safety awareness can have a profound impact on students and communities. These workshops can include hands-on activities, demonstrations of safety technologies, and discussions on responsible road behavior.
- **Hackathons and Competitions**: Hackathons and coding competitions centered around road safety challenges encourage students to collaborate and innovate. These events can lead to the development of new apps, devices, or systems that enhance road safety and raise awareness among participants.

By incorporating road safety into STEM education, students gain a deeper appreciation for the real-world applications of their learning. Engaging them through interactive tools like VR simulations and coding projects not only enhances their understanding but also nurtures their creativity and problem-solving skills. Outreach programs extend the impact of STEM education beyond the classroom, fostering a culture of road safety awareness that can have a lasting positive influence on both individuals and communities.

4. COLLABORATIVE APPROACH: STEM AND ROAD/TRAFFIC SAFETY EXPERTS

4.1 Partnerships between Educational Institutions and Industry

- **Collaboration on Research Projects**: Close ties between educational institutions and industry experts in road and traffic safety lead to collaborative research efforts. These partnerships enable the development of practical solutions and innovations that address real-world challenges, ensuring that academic knowledge translates into impactful outcomes.
- **Internships and Co-op Programs**: Providing students with opportunities for internships and co-op programs with road safety organizations or companies allows them to gain hands-on experience. These experiences bridge the gap between theory and practice, giving students a chance to contribute to meaningful projects and learn from seasoned professionals.

4.2 Multi-Disciplinary Research

- **Joint Efforts of Diverse Experts**: The complexity of road safety issues calls for multidisciplinary approaches. Collaboration between engineers, data scientists, urban planners, psychologists, and sociologists brings diverse perspectives to the table. These collaborative efforts yield comprehensive strategies that consider not only technological solutions but also behavioral and societal factors.
- **Holistic Road Safety Strategies**: Integrating insights from various disciplines results in holistic road safety strategies. For example, engineering innovations are combined with insights into driver behavior and cognitive psychology to create systems that not only prevent accidents but also account for human factors that contribute to safety.

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Collaboration between STEM education and road/traffic safety experts is instrumental in driving innovation and impactful change. The synergistic exchange of knowledge and expertise ensures that solutions are not only technically sound but also practical and tailored to the complexities of real-world challenges. By working together, these professionals amplify the potential for creating safer transportation systems that cater to the needs of individuals and communities.

5. CASE STUDIES: REAL-WORLD APPLICATIONS

5.1 Autonomous Vehicles

- **STEM Contribution to Self-Driving Cars**: STEM education plays a vital role in the development of autonomous vehicles. Engineers with expertise in robotics, artificial intelligence, and control systems design the complex algorithms that enable self-driving cars to navigate and respond to their environment. These vehicles have the potential to greatly reduce accidents caused by human error.
- **Impact on Road Safety and Traffic Management**: Autonomous vehicles, equipped with sensors and advanced algorithms, can predict and react to potential hazards faster than human drivers. This can lead to a significant reduction in accidents caused by factors such as distracted driving, speeding, and impaired judgment. Additionally, autonomous vehicles can communicate with each other and traffic management systems, potentially improving traffic flow and reducing congestion-related accidents.

5.2 Smart Infrastructure

- **Examples of Smart Traffic Signals**: STEM experts contribute to the design of smart traffic signal systems that dynamically adjust signal timings based on real-time traffic data. These systems optimize traffic flow, reducing the chances of accidents caused by sudden stops, congestion, or inefficient traffic management.
- **Positive Outcomes for Congestion Reduction and Accident Prevention**: Smart traffic management systems can help alleviate congestion, which often contributes to accidents. By optimizing traffic flow and reducing bottlenecks, these systems enhance safety by minimizing the likelihood of rear-end collisions and aggressive driving behaviors that arise from frustration with traffic congestion.

These case studies highlight the transformative potential of STEM education in real-world road safety applications. The development of autonomous vehicles and smart traffic infrastructure underscores how STEM-driven innovations can revolutionize transportation safety. By harnessing technology, data analysis, and multidisciplinary expertise, these advancements are not only changing the landscape of road safety but also offering glimpses of a future where accidents are significantly reduced and transportation systems operate more efficiently. The convergence of STEM and road safety expertise is driving the next generation of solutions that have the potential to reshape how we perceive and manage transportation risks.

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6. CHALLENGES AND FUTURE DIRECTIONS

6.1 Access to STEM Education

- **Addressing Disparities**: Ensuring equitable access to quality STEM education is a challenge. Socioeconomic disparities can limit access to resources and opportunities, hindering the development of a diverse pool of road safety innovators. Efforts are needed to provide underrepresented communities with equal access to STEM education, fostering a more inclusive and representative approach to road safety solutions.

6.2 Ethical Considerations

- **Balancing Technological Advancement and Ethical Implications**: As STEM-driven road safety technologies advance, ethical dilemmas arise. Issues such as data privacy, algorithm bias, and liability in cases of accidents involving autonomous vehicles need careful consideration. STEM education must incorporate ethical discussions to prepare future innovators to navigate these challenges responsibly.

6.3 Evolving Technologies

- **Adapting STEM Education to Rapid Technological Changes**: The rapid pace of technological evolution poses a challenge to STEM education. The curriculum must stay current to address emerging technologies and their implications for road safety. Educators need to ensure that students are equipped with the skills needed to adapt to and shape technological advancements.
- **Interdisciplinary Skillsets**: The complex nature of road safety issues requires professionals with interdisciplinary skillsets. Integrating diverse expertise, from engineering to psychology, poses challenges in terms of training individuals who can effectively bridge these gaps and collaborate to create comprehensive solutions.

Navigating these challenges is crucial for the ongoing success of the relationship between STEM education and road/traffic safety. As technology continues to reshape transportation and safety landscapes, proactive steps are needed to ensure that STEM education remains relevant, accessible, and ethically conscious. The ability to anticipate and address these challenges will determine the effectiveness of STEM-driven road safety innovations in the future. It is through these challenges that the true potential of STEM education in enhancing road safety will be realized, shaping safer and more efficient transportation systems for generations to come.

7. CONCLUDING REMARKS

The intersection of STEM education and road/traffic safety encapsulates the essence of innovation, awareness, and collaborative efforts aimed at creating a safer and more sustainable future. The relationship between these two realms is characterized by the fusion of science, technology, engineering, and mathematics with the practical imperatives of reducing accidents, saving lives, and enhancing transportation systems. By delving into the multifaceted aspects of this relationship, we have uncovered how STEM education serves as a driving force behind road safety innovation. From designing advanced vehicle safety technologies to optimizing traffic management systems, STEM professionals are at the forefront of creating solutions that address the complex challenges of road safety.

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Equally significant is the role of STEM education in fostering awareness and education. By integrating road safety topics into curricula, utilizing interactive learning tools, and conducting outreach programs, STEM education molds responsible citizens who understand the importance of adhering to road safety rules and contributing to accident prevention. Collaboration emerges as a central theme, illustrating the need for partnerships between STEM educators, researchers, and industry experts. The synergy of these diverse perspectives ensures that road safety solutions are not only technically robust but also contextually relevant and ethical. However, challenges persist. Ensuring equal access to STEM education, navigating ethical considerations, and keeping pace with evolving technologies require steadfast commitment and innovation. Overcoming these challenges is essential to fully unlocking the potential of STEM education to revolutionize road safety.

In conclusion, the integration of STEM education and road/traffic safety is not merely about academic concepts or technological advancements; it is a testament to human ingenuity and collaboration. It stands as a call to action for continuous investment in education and research, driving us towards a future where accidents are minimized, transportation systems are optimized, and communities thrive in safer environments. With determination, collaboration, and the application of STEM principles, we pave the way for a safer, smarter, and more sustainable road ahead.

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World Safety Organization (WSO)

The WSO was founded in 1975 in Manila, The Republic of the Philippines, as a result of a gathering of over 1,000 representatives of safety professionals from all continents at the First World Safety and Accident Prevention Congress. The WSO World Management Center was established in the United States of America in 1985 to be responsible for all WSO activities, the liaison with the United Countries, the co-operation with numerous Safety Councils, professional safety/environmental (and allied areas) organizations, WSO International Chapters/Offices, Member Corporations, companies, groups, societies, etc. The WSO is a non-profit, non-sectarian, non-political organization dedicated to: ***"Making Safety a Way of Life … Worldwide."***

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WSO develops and accredits educational programs essential to national and international safety and establishes centers to support these programs.

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EDUCATION (degree(s) held):	

REFERRAL
If you were referred by someone, please list his/her name(s), chapter, division, etc.:

WSO Member: __________

WSO Chapter: __________

WSO Division/Committee: __________

Other: __________

PLEASE specify your area of professional expertise. This information will be entered into the WSO "Bank of Professional Skills," which serves as a pool of information when a request for a consultant/information/expertise in a specific area of the profession is requested.

[ ] Occupational Safety and Health (OS&H)
[ ] Environmental Safety and Health (EH&S)
[ ] Fire Safety/Science (FS&S)
[ ] Safety/Loss Control Science (S&LC)
[ ] Public Safety/Health (PS&H)
[ ] Construction Safety (CS)
[ ] Transportation Safety (TS)
[ ] Industrial Hygiene (IH)
[ ] Product Safety (PRO)
[ ] Risk Management (RM)
[ ] Hazardous (Toxic) Materials Management (HAZ)
[ ] Nuclear Safety (NS)
[ ] Aviation Safety (AS)
[ ] Ergonomics (ERG)
[ ] Petroleum (PS)
[ ] Oil Wells (OW)
[ ] Other: __________

PAYMENT OPTIONS
For secure Credit Card Payment, please visit the SHOP on WSO's website (https://worldsafety.org/shop) and select "WSO Membership Application Fee" to make your payment. You will receive an emailed invoice for the Membership Fee upon approval.

Check or Money Order payable to WSO may be mailed with application packet to: WSO-WMC, Attn: Membership Coordinator, PO Box 518, Warrensburg MO 64093 USA. International postal money orders or bank drafts with a U.S. routing number are acceptable for applicants outside the United States. For alternate payment arrangements, please contact WSO-WMC.

Annual dues hereafter will be billed and payable on the anniversary date of your membership. **U.S. funds only.**

By submitting this application, you are accepting that WSO will use the information provided to perform an independent verification of employer, credentials, etc.

Mail or email completed form, along with current résumé/CV:

WSO World Management Center
PO Box 518 | Warrensburg, Missouri 64093 USA
Phone 660-747-3132 | FAX 660-747-2647 | membership@worldsafety.org

Student Membership Application

WORLD SAFETY ORGANIZATION

Instructions | Complete all applicable fields and mail to **WSO World Management Center, PO Box 518, Warrensburg, MO 64093 USA**, email to **membership@worldsafety.org**, or fax to **1-660-747-2647**. For assistance completing this application, please call **1-660-747-3132**, or email questions to **membership@worldsafety.org**.

Membership Level | Choose One

❑ **College/University Student Membership – FREE**

You will receive all member benefits including subscriptions to ***WSO World Safety Journal*** *and* ***WSO NewsLetter****, as well as access to* ***WSO's Mentor Program****.*

❑ **Middle/High School Student Membership – FREE**

You will receive all member benefits including subscription to ***WSO World Safety Journal*** *and* ***WSO NewsLetter****, excluding access to* ***WSO's Mentor Program****.*

Last Name/Family Name

First Name/Given Name ___ Initial ___ ❑ M ❑ F (Gender)

Birthdate MM / DD / YYYY *(Application must include exact birthdate with year to be processed.)*

Current Street Address ❑ On Campus ❑ Off Campus *(Attach separate sheet if you need more room for your address.)*

City ___ State/Province ___ Country

Zip/Postal Code ___ Telephone Number (including area code) ___ ❑ Landline ❑ Mobile (Type)

Permanent Street Address

City ___ State/Province ___ Country

Zip/Postal Code ___ Telephone Number (including area code) ___ ❑ Landline ❑ Mobile (Type)

Send mail to: ❑ Current Address ❑ Permanent Address

Email Address(es)

COLLEGE/UNIVERSITY STUDENT

Category: ❑ Undergraduate ❑ Graduate/Post-Graduate

Degree(s) Sought/Obtained

Name of College/University ___ Campus

MIDDLE / HIGH SCHOOL STUDENT

❑ I am a Middle Schooler in: ❑ 6th Grade ❑ 7th Grade ❑ 8th Grade

❑ I am a High School: ❑ Freshman ❑ Sophomore ❑ Junior ❑ Senior

Name of School

Approximate Date of Graduation (MM / YYYY)

(For High School and College/University students, application must include approximate date of graduation to be processed.)

If you were referred by someone, please list name(s), chapter, division, etc.:

WSO Member: ___

WSO Chapter/National Office: ___

WSO Division/Committee: ___

Other: ___

What Interests You?

Please specify your area(s) of interest. These areas of interest will allow you to connect with others who share similar interests throughout the world.

[ ] Occupational Safety and Health (OS&H)
[ ] Environmental Safety and Health (EH&S)
[ ] Fire Safety/Science (FS&S)
[ ] Safety/Loss Control Science (S&LC)
[ ] Public Safety/Health (PS&H)
[ ] Construction Safety (CS)
[ ] Transportation Safety (TS)
[ ] Industrial Hygiene (IH)
[ ] Product Safety (PRO)
[ ] Risk Management (RM)
[ ] Hazardous (Toxic) Materials Management (HAZ)
[ ] Nuclear Safety (NS)
[ ] Aviation Safety (AS)
[ ] Ergonomics (ERG)
[ ] Petroleum (PS)
[ ] Oil Wells (OW)
[ ] Other: ___

Required Signatures & Permissions

I subscribe to the above record and when approved will be governed by the Constitution and By-Laws of WSO and its Code of Ethics as I continue as a member. I furthermore agree to promote the objectives of the WSO wherever and whenever possible.

X ___ ___

Applicant Signature Date

FOR MID/HIGH SCHOOLERS ONY: WSO subscribes to the Family Educational Rights and Privacy Act (FERPA) philosophy in protecting student privacy and information. WSO may disclose "directory" information such as a student's name, WSO Student Chapter affiliation, name of school, grade in school, etc., along with group or individual photos in WSO NewsLetters, NewsFlashes, eNews, on WSO website, and on WSO's social media accounts.

❑ My student has permission to participate as outlined above.

❑ My student has permission to participate with exclusions:

X ___ ___

Parent/Guardian Signature (Mid/High Student) Date

X ___ ___

WSO Student Chapter Mentor Signature Date

[IF APPLICABALE]

WSO – National Offices

WSO National Office for Algeria
c/o Institut des Sciences et de la Technologie (I.S.T.)
attn.: Mr. Ferhat Mohia, Director
contact: ferhatmohia@yahoo.fr

WSO National Office for Australia
c/o Curtin University of Technology
attn.: Dr. Janis Jansz, Director
contact: j.jansz@curtin.edu.au

WSO National Office for Austria
c/o Payesh System Mehr Engineering Company
attn.: Dr. Majid Alizadeh, Director
contact: majidealizadeh@gmail.com

WSO National Office for Cameroon
c/o Cameroon Safety Services
attn: Mr. Clement B. Nyong, Director
contact: ny.clement@yahoo.com

WSO National Office for Canada
c/o Apex One Management Group
attn.: Mr. Michael Brown, Director
contact: michael.brown@worldsafetycanada.ca | mike@apexone.com
website: worldsafetycanada.ca

WSO National Office for Ghana
c/o Ghana National Fire Service
attn.: Mr. Peter Oko Ahunarh, Director
contact: pahunarh23@gmail.com

WSO National Office for India
c/o Indian Society of Safety Engineers (I.S.S.E)
attn.: Mr. T. Shankar, Director
contact: support@worldsafety.org.in

WSO National Office for Indonesia
c/o Prosafe Institute
attn.: Mr. Soehatman Ramli, Director
contact: soehatmanramli@yahoo.com

WSO National Office for Iran
c/o Payesh System Mehr Engineering Company
attn.: Mrs. Fatemeh Gilani, Director
contact: gilani@imsiran.ir

WSO National Office for Iraq
c/o NAYA Engineering Services & Training
attn.: Dr. Eng. Khaldon Waled Suliman, Director
contact: naya_engineering_services@yahoo.com

WSO National Office for Lebanon
c/o Ministry of Transport
attn.: Dr. Elias M. Choueiri, Director
contact: elias.choueiri@gmail.com

WSO National Office for Myanmar
c/o Win Oshe Services Co., Ltd
attn.: Mr. Win Bo, Director
contact: winbo@osheservices.com

WSO National Office for Nigeria
c/o DanaRich Creative Concept, LTD
attn.: Mr. Soji Olalokun, WSO-RSD, Director
contact: info@worldsafety.org.ng
website: worldsafety.org.ng

WSO National Office for Pakistan
c/o Greenwich Training & Consulting
attn.: Mr. Tayyeb Shah, Director
contact: doctimes@gmail.com

WSO International Office for Philippines
attn.: Engr Alfredo A. De La Rosa Jr., Director
contact: info@wsophil.org

WSO National Office for Saudi Arabia (KSA)
c/o The Academy of Sciences for Medical Education
attn.: Mr. Rocky Binuya, Director
contact: info@aos-ksa.com | binuya.rocky@gmail.com
website: https://aos-ksa.com/en

WSO National Office for United Arab Emirates (UAE)
c/o Tatweer Industrial Inspection & Training Services LLC
attn.: Miss Nazya Robin, Quality Manager & Director
contact: info@tiits.ae

WSO National Office for Vietnam
c/o Safety Training & Consulting Limited
attn.: Mr. Binh Pham, WSO-CSI(ML), Director
contact: binh.pt@worldsafety.org.vn
binh.pt@safety.edu.vn
website: worldsafety.org.vn

World Safety Organization
Code of Ethics

Members of the WSO,
by virtue of their acceptance of membership
into the WSO,
are bound to the following Code of Ethics
regarding their activities associated with the WSO:

Members must be responsible for
ethical and professional conduct in relationships
with clients, employers, associates, and the public.

Members must be responsible for professional competence in
performance of all their professional activities.

Members must be responsible
for the protection of professional interest, reputation, and
good name of any deserving WSO member
or member of other professional organization involved in
safety or associate disciplines.

Members must be dedicated to professional development of new
members in the safety profession
and associated disciplines.

Members must be responsible
for their complete sincerity in professional service to the
world.

Members must be responsible for continuing improvement and
development of professional competencies
in safety and associated disciplines.

Members must be responsible
for their professional efforts to support the WSO motto:

"Making Safety a Way of Life…Worldwide."

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www.worldsafety.org
info@worldsafety.org | elias.choueiri@gmail.com