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ORIGINAL ARTICLE

Weather-Related Trends in Drug Use Incidents Aboard Transit Vehicles

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Abstract With changing trends in drug misuse in the United States, including the increased prominence of fentanyl misuse, transit operators have indicated concern that people who use drugs (PWUD) seek transit vehicles as shelter to escape from inclement weather. Research has yet to investigate the relationship between drug misuse on transit vehicles and weather conditions. We hypothesized that there would be a higher frequency of drug use incidents on transit vehicles during periods of reduced daylight hours, low temperatures, high precipitation, or high wind speeds. Using a dataset of drug use incidents reported by transit operators in King County, Washington, in 2022 ($n = 1518$), we descriptively characterized the frequency of daily drug use incidents. We used a Poisson regression model to further understand the association between daily incident count and daily weather patterns. Reported drug use incidents showed clear temporal trends, with a higher frequency of incidents in winter and spring than in summer; April had the highest mean daily incident count of 7.3 incidents/day. Higher temperature was significantly associated with lower incident count (IRR, 0.96; 95% CI, 0.95, 0.97). Daylight hours were also significantly positively associated with higher incident counts (IRR, 1.14; 95% CI, 1.11, 1.17). The findings of this study support the hypothesis that drug use incidents are more common on days with lower temperatures. These results can help guide the timely deployment of interventions, informed by drug use patterns, to reduce drug use incidents on transit and reduce operator and passenger exposure to secondhand drug use.

Keywords Substance misuse · Public transit · Weather-related trends · Temporal trends

Introduction

Over the past decade, trends in drug misuse in the United States have changed, including increasing prominence of fentanyl misuse in the Pacific Northwest [1–4]. In Washington State, this drug use often occurs in public indoor spaces, such as public transit vehicles [5]. Reports from transit operators and data from transit agencies have indicated that these drug use incidents occur regularly on public transit vehicles [5, 6]. Previous research has shown that drug use on transit vehicles creates potential for transit operators and the riding public to experience secondhand exposures to these drugs [7]. It is therefore necessary to understand factors that contribute to

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drug use aboard transit vehicles to design effective interventions.

Research has shown that drug use in the United States tends to be more prevalent during periods of warmer temperatures [8]. Data from the Washington State Department of Health has indicated that from 2019 to 2023, drug-related emergency department visits and emergency medical services responses peaked during the second and third quarters of the year, aligning with the warmer months of the year [9]. These trends may be due to increased access to drugs and a higher rate of drug use initiation during summer [10].

Despite these trends, transit operators have indicated concern that people who use drugs (PWUD) seek transit vehicles as shelter to escape from inclement weather [5], which could result in higher rates of drug use incidents on transit vehicles in periods of poorer weather conditions. While research has yet to investigate if there is a relationship between inclement weather and drug use incident frequency on transit vehicles, it is well-documented that unhoused populations are simultaneously more likely to seek shelter in colder weather [11] and disproportionately impacted by substance misuse [12–14]. Exacerbated by the lack of access to safe consumption sites [15–18], it is possible that the convenience of transit vehicles for drug use may result in PWUD using on these vehicles during periods of low temperatures, high precipitation, or high wind speeds. It is also possible that in winter months with less daylight, transit vehicles provide a well-lit environment to facilitate drug consumption; however, research has yet to investigate this relationship.

While ridership on transit vehicles, both across the United States and specifically in King County, WA, experienced a sharp decline between 2020 and 2022 due to the COVID-19 pandemic, these rates have been increasing since 2022 and have been recovering towards pre-pandemic rates [19, 20]. As drug misuse has also increased during this time [1, 2], examining trends in drug use incidents on transit vehicles in 2022 can be an effective starting point in informing policy interventions to protect transit operators and public health. To date, there is no research characterizing temporal and weather-related factors that contribute to the frequency of drug use incidents on transit vehicles. This information can help guide targeted interventions to protect operators and the riding public on higher risk routes during peak times for drug use on transit.

This study characterizes the frequency of drug use incidents on public transit vehicles in King County, Washington (USA) in 2022, and investigates temporal and weather factors that may be associated with the frequency of drug use incidents, such as daylight hours, temperature, precipitation, and wind speed. We hypothesized that on days with fewer daylight hours (i.e., winter months rather than summer months), drug use is more likely to occur on transit vehicles, as vehicles provide a well-lit environment to facilitate drug consumption. Furthermore, we hypothesized that PWUD are more likely to use drugs on transit vehicles during poorer weather conditions (lower temperatures, higher wind speeds, and more precipitation). To date, no research has investigated how weather and daylight conditions relate to drug use incident frequencies, and the results of this study can guide the timely interventions that reduce the occurrence of drug use on transit vehicles, therefore protecting operators and the riding public from secondhand exposures.

Methods

Dataset

This study used a dataset of drug use incidents reported by transit operators in King County, Washington in 2022 ($n = 1518$), which includes details about each incident (date, vehicle type, and a free-text description of the incident). This dataset was provided to researchers by a transit company in King County, Washington; researchers reviewed this dataset to ensure all data was related to drug incidents.

We used this dataset to tabulate the daily frequency of incidents from January 1 to December 31, 2022. Using publicly available weather data [21], we identified the temperature (daily maximum and daily minimum), precipitation (quantity of rain/melted snow/snow/ice/hail), and average wind speed on each day in 2022 in King County, taken from one weather station at Boeing Field in central King County. Average daily temperature was calculated as the mean of the daily maximum and daily minimum temperature. We also collected daylight hours data for 2022 from the National Centers for Environmental Information [22]. These variables were selected to test the hypothesis that low temperatures, high precipitation, high wind speeds, and reduced daylight outdoors are associated

Table 1 Summary of variables included in analysis

Variable	Calculation (if applicable)	Source
Daily count of drug use incidents	Count per day	Dataset of drug incidents
Latitude and longitude of incident	Provided from source	Dataset of drug incidents
Date of incident	Provided from source	Dataset of drug incidents
Average daily temperature (F)	Mean of daily maximum and daily minimum temperature	[21]
Precipitation (in)	Provided from source	[21]
Average wind speed (mph)	Provided from source	[21]
Daylight hours (h)	Provided from source	[22]
Average weekday ridership every month	Provided from source	[20]

with higher rates of drug use incidents on transit vehicles. The final dataset for analysis consisted of date, number of incidents, temperature values, quantities for precipitation, wind speed, and daylight hours; these variables are summarized in Table 1.

Analysis

All data analysis was conducted using R statistical software [23]. Data were first analyzed descriptively. We visually depicted the trends in daily frequency of reported incidents by plotting the number of incidents reported each day. We developed summary tables, including total counts, means, standard deviations, and ranges for the number of reported incidents per day, and trends in daily weather and daylight conditions.

We developed scatterplots with smooth locally estimated scatterplot smoothing (LOESS) lines to visually examine the relationship between the frequency of incidents per day and (a) average daily temperature, (b) precipitation, (c) wind speed, and (d) daylight hours. This also helped check for linearity, to determine if data transformations (such as log-transformations) were needed. Weather variables were compared to each other using Pearson's correlation coefficients to determine if any were highly correlated; we defined a strong correlation as Pearson's $r > 0.7$, a fair correlation as $r > 0.3$, and a weak correlation as $r < 0.3$ [24].

We ran Poisson regression models for the daily count of reported drug use incidents in 2022. First, we constructed bivariate models for each weather variable (average daily temperature, wind speed, precipitation, and daylight hours). Then, we developed a full model, in which we included average daily temperature, wind speed, precipitation, and daylight hours as covariates. In all models, we controlled for the day of week to account for variability in transit service hours on weekends, using the weekday with the most incidents as the reference group. The average weekday ridership for each month, collected from publicly available data published by the transit agency [20], was included as a log-transformed offset term in all models, thereby accounting for potential differences in ridership count in different months. Offset terms are not estimated by the model, but rather standardize the incident count data across differing ridership numbers [25, 26]. Model fit was assessed using Akaike Information Criterion (AIC) and Bayesian Information Criterion; lower values indicated improved fit when compared to bivariate models. Variance inflation factors (VIFs) were calculated to check for multicollinearity; any variables with $VIF > 5$ were excluded from the model. Estimates from the regression model were exponentiated to calculate incidence rate ratios (IRR). 95% confidence intervals were calculated using the Wald method, and statistical significance was assessed using Wald tests.

Results

From January 1 to December 31, 2022, 1518 drug misuse incidents were reported (mean daily incident count = 4.2 incidents/day). One coach route, between Tukwila and Federal Way, had disproportionately more incidents, accounting for 31.8% of all reports in 2022 (483 incidents); however, two other routes in South King County and one route in North King County also had over 50 incidents each.

Figure 1 shows a time-series plot of daily reported incident counts, and Table 2 summarizes reported incident counts by month. The highest number of incidents was reported in April ($n = 219$), with an average daily count of 7.3 incidents. The lowest number of incidents was reported in December ($n = 40$), with an average daily count of 1.3 incidents. Table 3 summarizes weather and daylight conditions by month. Daylight and temperature values were highest in summer months and lowest in winter months, while wind was highest in winter and spring and precipitation was highest in winter.

Scatterplots of daily incident counts versus weather and daylight conditions, with smooth LOESS curves and the 95% confidence intervals, are shown in Fig. 2; these plots also include a linear model for comparison. Temperature had a slightly

Table 2 Distribution of drug incident counts by month in King County in 2022 ($n = 1518$)

Month	*N*	Lowest daily count	Highest daily count	Mean daily count	SD^
January	138	1	10	4.5	2.4
February	184	1	15	6.6	3.5
March	174	1	11	5.6	2.4
April	219	2	20	7.3	3.8
May	188	1	15	6.1	3.2
June	132	0	10	4.4	2.6
July	76	0	6	2.5	1.8
August	63	0	6	2	1.6
September	89	0	9	3	2.7
October	104	0	11	3.4	2.6
November	101	0	9	3.4	2.3
December	40	0	6	1.3	2

*SD^* standard deviation

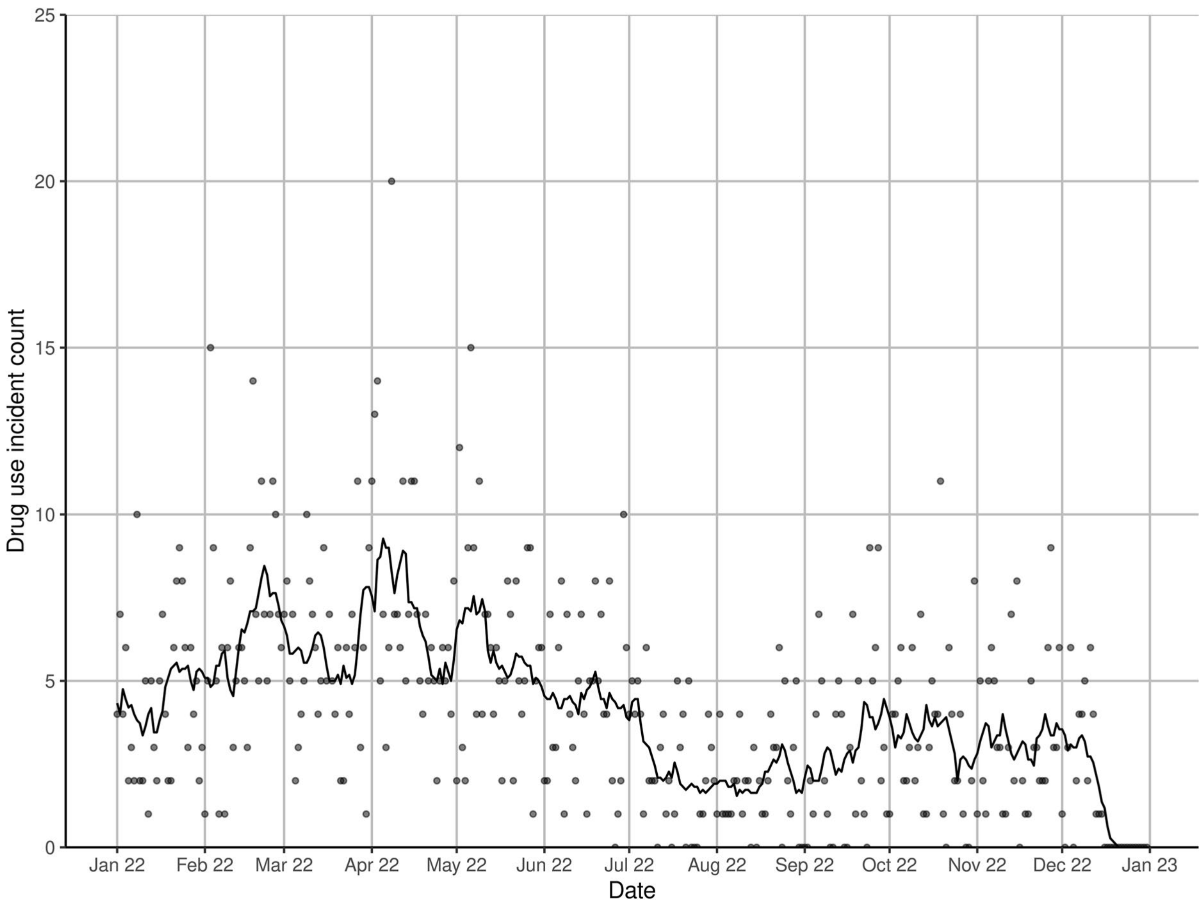

Fig. 1 Time-series plot of daily reported drug incident counts in King County in 2022 ($n = 1518$)

Table 3 Weather and daylight by month in King County in 2022

Month	Avg. daily Temp (F) Range Mean (SD^)	Daily precipitation (inches) Range Mean (SD^)	Avg. wind speed (miles per hour) Range Mean (SD^)	Daylight (h) Range Mean (SD^)
January	25.0–49.5 41.0 (5.0)	0–1.3 0.1 (0.3)	0–12.3 4.4 (2.9)	8.5–9.5 9.0 (0.3)
February	30.0–51.5 42.5 (5.2)	0–1.4 0.1 (0.3)	2.0–10.1 5.1 (2.4)	9.6–11.0 10.3 (0.4)
March	37.0–57.0 47.4 (4.4)	0–0.4 0.1 (0.1)	1.1–9.6 4.8 (2.1)	11.1–12.8 11.9 (0.5)
April	40.5–59.5 47.7 (4.5)	0–0.4 0.1 (0.1)	2.9–14.5 6.5 (2.8)	12.9–14.4 13.7 (0.5)
May	46.0–60.5 53.2 (3.9)	0–0.5 0.1 (0.1)	1.8–12.1 5.2 (2.4)	14.5–15.7 15.2 (0.4)
June	54.5–75.5 61.7 (5.1)	0–0.9 0.1 (0.2)	2.0–9.4 4.6 (1.8)	15.7–16.0 15.9 (0.1)
July	56.0–80.0 68.9 (5.9)	0	2.9–7.6 4.3 (1.1)	15.0–15.9 15.5 (0.3)
August	63.0–79.5 69.9 (4.0)	0	2.7–8.5 4.6 (1.4)	13.4–14.9 14.2 (0.5)
September	59.0–71.0 64.8 (2.9)	0	1.8–10.5 4.2 (1.8)	11.7–13.3 12.5 (0.5)
October	47.0–66.0 57.0 (5.9)	0–0.6 0.1 (0.1)	1.1–12.3 4.3 (2.9)	10.0–11.7 10.8 (0.5)
November	33.5–50.5 41.2 (3.4)	0–1.0 0.2 (0.3)	0.7–12.5 4.2 (2.9)	8.8–10.0 9.3 (0.4)
December	20.5–51.0 38.8 (6.9)	0–1.0 0.2 (0.2)	0.4–12.1 4.9 (3.2)	8.4–8.7 8.5 (0.1)

*SD^* standard deviation

negative relationship with incident count such that there were fewer incidents with increasing temperatures, while wind speed had a slightly positive relationship with incident count. These scatterplots show that, for the most part, the linearity assumption is met, suggesting that no transformations were needed.

Correlation coefficients showed a strong correlation between temperature and daylight ($r = 0.71$), and a fair correlation between wind speed and precipitation ($r = 0.31$); all other variables showed weak correlation.

Table 4 shows results from our bivariate Poisson regression models. Higher temperature was significantly associated with lower incident count, such that a 1 degree Fahrenheit increase in temperature was associated with a 2% decrease in the expected reported drug use incident count (IRR, 0.98; 95% CI, 0.98, 0.99). Wind speed was significantly associated with higher incident counts, such that a 1 mph increase in wind speed was associated with a 25% increase in the expected reported drug use incident count (IRR, 1.25; 95% CI, 1.05, 1.47). Table 5 shows results from our full Poisson regression model. Accounting for other covariates, higher temperature remained significantly associated with lower incident count (IRR, 0.96; 95% CI, 0.95, 0.97); however, wind speed was no longer significantly associated with incident count (IRR, 1.02; 95% CI, 1.00, 1.04), indicating that the variance attributed to wind speed in the bivariate model was explained by the other weather variables. In the full model, number of daylight hours was significantly associated with higher incident counts, such that a 1 h increase in daylight hours was associated with a 14% increase in the expected reported drug use incident count (IRR, 1.14; 95% CI, 1.11, 1.17). The full model yielded lower AIC and BIC values compared to bivariate models,

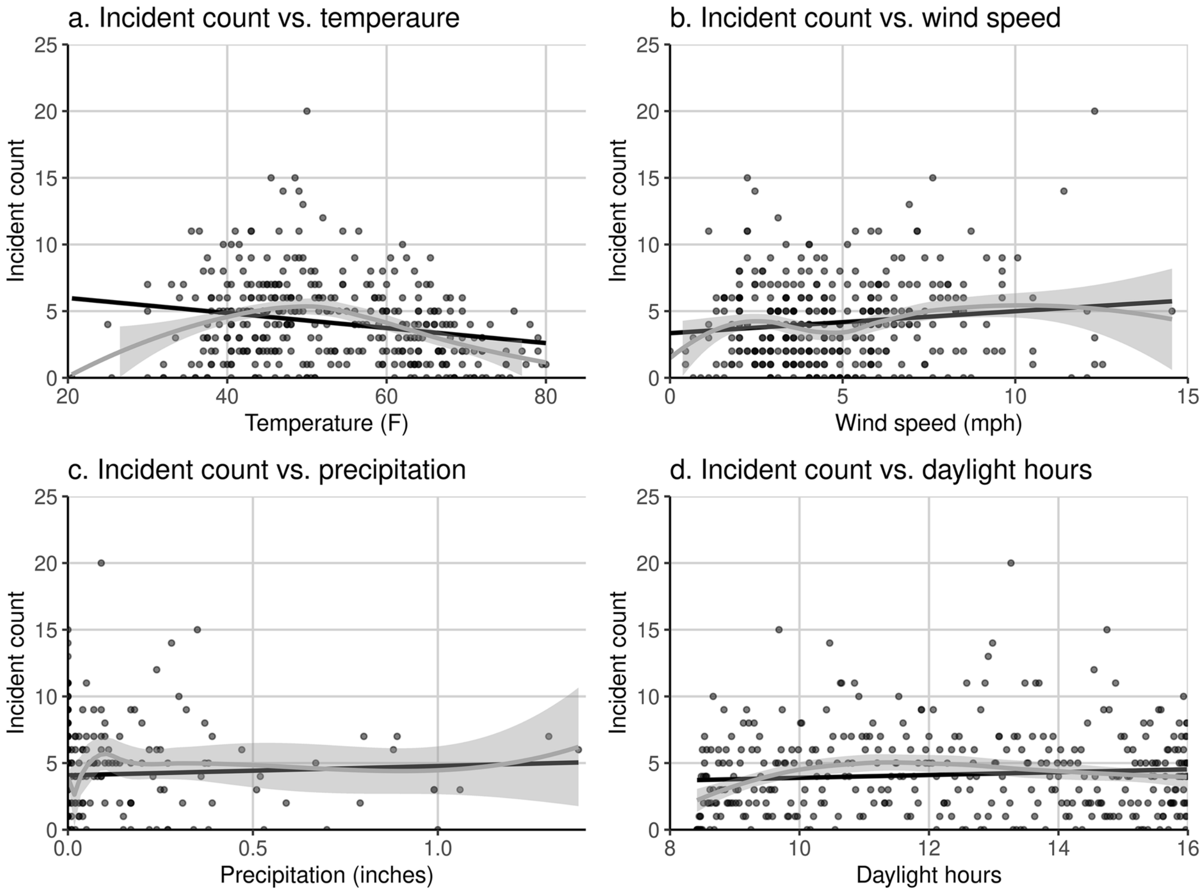

Fig. 2 Scatterplots with smooth LOESS curves of daily incident counts vs. weather and daylight conditions in King County in 2022: **a**. incident count vs. temperature; **b**. incident count vs. wind speed; ***c***. incident count vs. precipitation; and **d**. incident count vs. daylight hours. Shaded region represents 95% confidence intervals. Gray line represents the smooth LOESS curve, while black line represents a linear model for comparison

Table 4 Bivariate Poisson regression models for drug use incident count ($n = 365$ days)

Predictors	Incidence rate ratio	95% confidence interval
Average daily temperature (F)	0.98*	0.98, 0.99*
Precipitation (inches)	1.23	0.95, 1.56
Average wind speed (mph)	1.25*	1.05, 1.47*
Hours of daylight	1.01	0.99, 1.03

The asterisk "*" indicates $p < 0.05$, calculated using Wald test

suggesting improved overall model fit. All variables in the model had VIF < 5, suggesting that any concern for multicollinearity was not severe enough to adjust the model.

Table 5 Full Poisson regression model for drug use incident count ($n = 365$ days)

Predictors	Incidence rate ratio	95% confidence interval
Average daily temperature (F)	0.96*	0.95, 0.97*
Daily precipitation (inches)	1.01	0.76, 1.33
Average daily wind speed (mph)	1.02	1.00, 1.04
Hours of daylight	1.14*	1.11, 1.17*
Day of week (REF: Friday)		
Monday	0.96	0.80, 1.15
Tuesday	0.98	0.81, 1.17
Wednesday	0.84	0.69, 1.01
Thursday	0.89	0.74, 1.08
Saturday	0.91	0.75, 1.10
Sunday	1.01	0.84, 1.22

The asterisk "*" indicates $p < 0.05$, calculated using Wald test

Discussion

In recent years in Washington state, drug use on transit has resulted in potential secondhand exposures among transit operators and the riding public [5–7]. Transit vehicles provide shelter for PWUD to escape from inclement weather [5], making for a convenient space to use drugs in the absence of access to safe consumption sites [15–18]. These trends may have also been exacerbated by changes in Washington state law between 2021 and 2023 regarding public drug use [27].

This study found that one coach route accounted for nearly a third of all reported drug use incidents. While this specific route and its characteristics are unique to King County, WA, the existence of drug use hotspots is common in other major cities in the United States [28]. Therefore, it is likely that other cities exhibit similar patterns in drug use on transit, where specific routes experience disproportionately higher rates of drug use.

Reported drug use incidents on transit in 2022 in King County demonstrate clear temporal trends, with April being the peak month for reports to be filed. While December had the lowest counts, it is possible that this is due to underreporting during the holiday season. Aside from this deviation in December, we observed clear trends with the highest incident counts in spring, and the lowest counts in late summer, suggesting potential seasonal trends in reporting drug use. In our regression model, we found that daylight hours were significantly positively associated with drug use incident counts; however, this may also be due to the low counts in December and potentially underreporting during the holiday season. This relationship with daylight hours contrasts with our hypothesis, as we expected that on days with fewer daylight hours, PWUD would be more likely to use drugs in well-lit areas like transit vehicles, which would be reflected through increased reports on those days. It is unclear whether increased daylight hours in spring are a cause of increased incident counts, or if another unmeasured variable (such as increased drug availability in certain times of the year [10]) is the reason for the association between daylight hours and incident counts.

Consistent with transit operator reports, we found that the number of reported drug use incidents were related to weather conditions. Scatterplots of incident counts against weather conditions showed that wind speed had a positive relationship with incident counts, supporting our hypothesis that, as outdoor windspeeds increase, it would be more difficult to smoke drugs, driving PWUD indoors and onto transit. Temperature was negatively related with incident counts, which supports our hypothesis that, as the outdoor temperature is colder, PWUD prefer to use drugs in indoor spaces such as transit vehicles, which are warmer. While warmer spring months showed a peak in the raw count of reported drug use incidents, when accounting for ridership, our regression model showed that the IRR of drug use incidents on board transit is higher in colder months when all other weather covariates were controlled for. In our regression model, we found that temperature had a significant association with incident counts, where a 1 degree Fahrenheit increase in temperature corresponded to a 4% decrease in the expected drug use incident count for the same amount of ridership. Comparing the hottest day in 2022 (average temperature of 80.0 °F) to the coldest day (average temperature of 20.5 °F), we could expect up to 238% higher reported drug use incident counts in colder seasons than warmer seasons if all other weather conditions remain unchanged. This highlights the need to focus interventions on colder days, as these are the days where there is the highest likelihood of drug use incidents on transit vehicles, assuming the reporting is an appropriate proxy measure for actual use.

Research conducted by the U.S. Federal Transit Administration (FTA) found that 68% of urban transit systems were in need of interventions to reduce safety risks towards workers [29]; while this study was focused on general safety, many of its findings remain applicable to passenger drug misuse incidents. Across transit agencies in the United States, the most prevalent interventions were focused on increased education, awareness, and surveillance [29]. While these interventions may be impactful, they do not explicitly eliminate the hazard itself in the context of passenger drug misuse incidents, which per the hierarchy of controls is the most effective method to promote a hazard-free workplace [30]. The FTA report identified other interventions that have lower rates of implementation, such as protective barriers for the operator area or improved security patrolling to remove passengers that pose a risk [29]; these interventions do reduce the likelihood of exposure to the hazard from the workplace, and when implemented, exhibit high rates of effectiveness [29]. These interventions can also protect the riding public from secondhand exposures, and create a safer transit environment overall.

Transit operators are not equipped to handle drug use incidents on board their vehicle; however, it remains important that interventions to protect operators and the riding public are implemented without further stigmatizing PWUD. While it is not possible to intervene on the weather, it is possible to intervene on the need for PWUD to escape inclement weather. Per the hierarchy of controls [31], eliminating a hazard is the most effective control; this means removing drug use from transit vehicles. Therefore, on days with low temperatures and inclement weather, proactive efforts to redirect PWUD to other forms of shelter can reduce the likelihood of drug use incidents on transit. However, research has shown that arresting PWUD is not an effective solution, as these traditional policing methods are associated with higher risks of future overdoses [32]. Instead, providing access to programs that move PWUD to treatment pathways rather than incarceration have been shown to have greater effectiveness in decreasing future drug use [33].

PWUD who are unhoused in King County, WA, currently have limited recourse to seek shelter. Safe consumption sites may provide alternatives for PWUD who seek shelter, while also offering medical professionals and resources for those who use drugs [16]. Despite social stigma and governmental pushback over the implementation of safe consumption sites [16], these sites have been shown to reduce mortality risks and reduce harm to PWUD [17, 18, 34]. Similarly, promoting shelters for the unhoused that adopt harm reduction strategies can be useful for PWUD who want to escape inclement weather. Housing First initiatives, which aim to provide shelter to unhoused populations without any conditions regarding substance misuse, have been shown to be successful in reducing rates of homelessness, while not increasing rates of substance misuse [35]. While there are no safe consumption sites and few harm reduction shelters in King County, the promotion and development of such sites may be highly impactful in reducing the frequency of drug use on transit vehicles. Such interventions can not only improve the well-being of transit operators and the safety of passengers but can also reduce drug overdoses in the community by providing access to medical care for PWUD [17, 18, 34], aligning with public health goals in King County, Washington State, and the United States [36, 37].

This work provides a starting point for research that investigates the relationship between weather and drug use on transit. The clear temporal trends can inform transit operators and their employers on when to deploy interventions such as increased personal protective equipment or increased security. Furthermore, as temperature had a clear relationship with incident counts, efforts to reduce drug use on transit can be focused more on days with lower temperatures. In sum, the results here provide another tool to guide policy and interventions that reduce drug use on transit and protect both transit operators and the riding public.

Limitations

This study has some limitations. As this study only uses data from King County, WA, the findings of this study may not be generalizable to transit systems in different regions or different weather conditions, where trends in drug misuse on transit vehicles and its relationship to weather may vary. In more extreme weather conditions, the relationship between weather and incident counts may not follow the same linear trend observed in the weather range of this study. This study is also not generalizable to other types of transit workers such as maintenance personnel, who may have different exposures to drug paraphernalia and residue, and therefore, may require different interventions. While we had access to a number of weather-related variables, all weather data was taken from one weather station in King County, as other weather stations did not have complete sets of data. Given that weather trends can vary in different regions of King County, this may have impacted our ability to develop a more accurate regression model. Our analysis does not allow us to consider weather and daylight at the specific time of the incident given that the outcome is the day-level count of drug misuse incidents. It is possible that there is within-day variability in when drug misuse incidents occur that we could not capture in this analysis. Future analysis could seek to better characterize these drug misuse on transit at finer temporal resolution.

Furthermore, our initial dataset was likely affected by underreporting, as there is no way to ensure that transit operators notice or report incidents. Operators on busier routes may have greater difficulty spotting drug use incidents, and those on routes where drug misuse is prevalent might opt to not report every incident. This study also does not consider variables other than weather and daylight that may the frequency of drug misuse on transit vehicles. These factors likely impacted the estimates from our regression model.

Conclusions

This study is the first to describe drug use incident trends on transit vehicles in King County, and investigate the relationship between weather and daylight conditions and incident counts. Our study found temporal trends in drug use incident frequency, and that temperature is likely related to drug use incident counts, supporting our hypothesis that lower outdoor temperatures are associated with greater drug use on transit vehicles. The findings here provide direction for transit operators and transit agencies on when and where to focus interventions that reduce drug use incidents (e.g., increasing security) and reduce operator and public exposure to secondhand drug use (e.g., using personal protective equipment).

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Author Contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Pranav Srikanth and overseen by Marissa Baker. The first draft of the manuscript was written by Pranav Srikanth, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability The data that support the findings of this study may be available from the senior author upon reasonable request.

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