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Reducing Distracted Driving and Improving Consistency with Brine Truck Automation

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Abstract: Salt brine is routinely used by transportation agencies to pre-treat critical infrastructure such as bridges, ramps, and underpasses in advance of winter storms. This requires an operator turning on and off brine controls while driving at highway speeds, introducing driver distraction and consistency challenges. In urban areas, such as Indianapolis, a 5500-gallon tractor trailer with a gross vehicle weight of 80,000 pounds is typically used and the driver may have 1200 on/off activations while covering 318 miles during a pre-treatment shift. This study conducted in collaboration with Indiana Department of Transportation has worked with their truck upfitters to adapt geo-fenced agriculture spraying controls to seven trucks that use the Global Positioning System (GPS) position of the truck to activate the sprayer valves when the trucks enter and exit geo-fenced areas that require pre-treatment. This automated brine system enhances safety, reduces driver workload, and ensures the consistent application of brine in designated areas. Furthermore, as additional environmental constraints and reporting requirements evolve, this system has the capability of reducing application rates in sensitive areas and provides a comprehensive geo-coded application history. The Indiana Department of Transportation has scaled deployment for treating interstates and major arterials with brine. This deployment on 5500-gallon tankers, used on I-64/65/69/70/74, and 465, eliminates over 10,000 driver distraction events during every statewide pre-treatment event.

Keywords: distracted driving; automation; winter operations; brine application

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1. Introduction

Over 70% of the United States (US) population live in regions that receive winter precipitation, or areas that average at least 5 inches of snow annually [1]. Winter weather conditions are difficult for drivers to navigate due to rapidly changing visibility and roadway conditions [2,3]. To help mitigate the impact of winter weather on roadways, agencies spend upwards of USD 2.3 billion nationwide on winter weather operations activities that include plowing, de-icing chemicals, and anti-icing chemicals [1]. During some of the worst driving conditions in which officials recommend the public to avoid driving, winter maintenance operators must be on the roadway to maintain mobility.

Figure 1 shows a few examples of the conditions that winter operation maintenance crews often face. Figure 1a shows blowing snow, reducing the visibility of the roadway surface with obscured roadway visibility. Figure 1b shows a traffic camera from I-65 with one direction of travel at free flow, while the other direction is congested. This shows the importance of winter maintenance crews during a winter storm event as mobility and vehicles are on the roadway regardless of weather. Figure 1c is an image from an Indiana Department of Transportation (INDOT) snowplow dash camera. This image depicts normal operating conditions, including operating the vehicle, managing winter operations equipment, and adhering to the surrounding traffic. The combination of winter weather and traffic conditions alone is difficult enough for the general public to navigate safely, but winter operation crews are required to routinely share their attention between navigating the roadway and operating controls in their truck for applying salt, deicing chemicals, and plow position. The goal of this project was to reduce driver distraction and workload for winter operation crews by automating their preventative anti-icing brine material application rates and start/stop locations.

(**a**)

(**b**)

(**c**)

Figure 1. Motivation for development of automatic material application. (**a**) Blowing snow—limited visibility of roadway. (**b**) ITS traffic camera—congestion during a winter storm. (**c**) Snowplow automatic vehicle location image—congestion during a winter storm.

2. Current Anti-Icing and De-Icing Practices

Most agencies use solid material for de-icing chemicals on their road network during a winter storm event and use brine for pre-treatment anti-icing [4,5]. Brine is usually more effective than rock salt for anti-icing pretreatment as the material adheres to the road surface. In contrast, the scatter and bounce of rock salt on a dry road often results in substantial waste. Indiana brine application varies from slide-in 1000-gallon brine tanks in their dump beds on smaller routes to large 5500-gallon tankers on high volume interstates. Figure 2 shows one of many brine tankers in the agency's fleet. Figure 2a shows the tractor where the operator drives and operates the system and Figure 2b shows the application equipment and nozzles in the rear. In Figure 2b, a left spray bar, right spray bar, and center spray bar can be seen as callout i, ii, and iii, respectively. These options enable the operator to manage applications in both the travel lane (callout iii), as well as short duration applications in adjacent lanes (callout i, ii) and adjacent exit/entrance ramps. Callout iv shows the control box for the solenoid that controls each valve for the respective spray bar.

(**a**)

(**b**)

Figure 2. Brine application equipment. (**a**) Brine application vehicle. (**b**) Brine application nozzles.

An example of brine application can be seen in Figure 3. Depending on the type of winter storm, the agency has three types of anti-icing procedures, including no application of brine, which usually occurs if rain is predicted in advance of the storm, spot treatment of bridge decks and underpasses as they are prone to freezing first, and complete application on all roadways and lanes. Figure 3a shows an example of spot treatment with the brine tanker applying material on the bridge deck from the center, and the right spray bar (Figure 2b, callouts ii and iii) capturing both lanes in a single pass. Figure 3b demonstrates the application of material on an underpass from the left and center spray bar (Figure 2b, callouts i and iii).

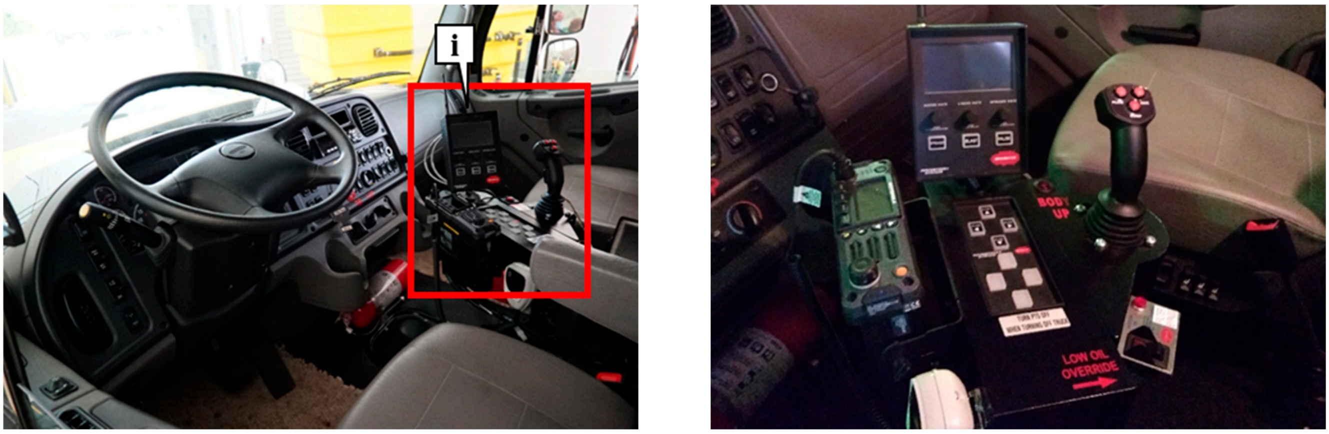
(**a**)

(**b**)

Figure 3. Brine application example locations. (**a**) Brine application on bridge decks. (**b**) Brine application on underpasses.

A challenging aspect for operators to pre-treat roadways is safely and accurately operating the controls as they travel interstate routes at approximately 60 mph with a substantial number of passenger cars and trucks that may be attempting to pass them on either the left and/or right (Figure 3a,b). The difficulty comprises several factors including operating vehicles weighing almost 80,000 lbs on urban interstates, a vehicle that experiences brake lag, as do all commercial truck air brake systems [6], a vehicle that is surrounded by adjacent traffic and that is making frequent lane changes and passing maneuvers, and, on I-465, the operators are expected to reach over on average every 0.5 miles (30 s) to activate the brine (turn on) and deactivate the brine (turn off) at every bridge deck and underpass.

An example of a manual operating controller can be seen in Figure 4. Figure 4a provides a driver's point of view where the driver operates the vehicle, manages and navigates surrounding traffic, and operates the controller (callout i). Figure 4b shows greater detail of the current manual operating controllers. Manual brine application can be very taxing to the driver as they are also expected to track the location of the upcoming application zones and begin applying, which often causes inconsistencies in application and subjects the driver to enhanced distracted driving. Distracted driving for the purposes of this study and as defined by the National Highway Traffic Safety Administration (NHTSA) refers to any instance wherein the driver has to take their attention away from driving, which includes, "talking or texting on your phone, eating and drinking, talking to other people in your vehicle, fiddling with the stereo, entertainment or navigation system" [7,8].



(**a**) (**b**)

Figure 4. Typical in-cab control panel of a winter operations truck. (**a**) Driver perspective. (**b**) Operating controller.

3. Distracted Driving Literature

In 2021, the National Highway Traffic Safety Administration (NHTSA) estimated that around 43,000 fatalities occurred on US roadways due to motor vehicle crashes and that 3522 fatalities (around 8.2%) of the crashes were due to distracted driving [9]. Studies have extensively looked at several factors that lead to distracted driving, most notably the use of cellphones and electronic devices [10–14]. Although most of these studies have used survey and interview-based approaches, these methods have certain limitations in capturing the external factors such as weather conditions and traffic/roadway characteristics that could lead to distracted driving. Several studies have used driving simulators and behavioral models to understand the impact of these external factors and how these distractions affect the driver's behavior [15–19].

Distracted driving is also a concern for agencies and the Department of Transportation (DOT) during roadside maintenance and winter operations where the drivers are simultaneously required to perform additional visual, manual, and cognitive tasks while driving. During winter operations, drivers interact with additional controls for plowing, brining, and spreading material. These operations require interactions with several controls and could lead to possible distractions while driving. Several agencies have deployed virtual reality and snowplow driving simulators to train their drivers and also to understand the impact of distracted driving while operating the controls [20–23]. A research study conducted at Arizona DOT found that drivers face higher workloads during winter operations where they need to perform several simultaneous tasks such as clearing the windshield while downshifting, answering radio calls, and monitoring the temperature gauge [22].

While "crash statistics for snow removal vehicles are hard to come by, as no federal agency currently tracks these types of accidents", data from several states suggest hundreds of snow removal vehicles are involved in crashes every year [24]. Iowa reported that for five winters between 2009 and 2014, there were 230 such accidents or an average of 46 per year [25]. Zockaie et al. reviewed UD-10 Crash Report Forms in Michigan for calendar years 2012 to 2017 and found 1354 crashes involving snowplows with the highest contributing factor being inattention/misjudgment by snowplow drivers, which accounted for 38.4% of the crashes [26].

A few agencies have developed driver assistance systems (DASs) to aid drivers during winter operations. A driver assist interface was developed in the early 2000s that provided visual information on lane edges, lateral position, and forward collision warnings to snowplow drivers in California [27]. Researchers from the University of Minnesota collaborated with Minnesota DOT and evaluated the application of Vehicle-to-Vehicle (V2V) communication for coordinated plowing, a radar-based backup assist system for operations and lane boundary guidance using a Global Navigation Satellite System (GNSS) for navigation assistance during poor visibility [28].

4. Opportunity to Adapt Agricultural Technology

For decades, intelligent sprayers have been used in precision agriculture to increase crop yields and aid in management decisions. [29–31]. The development of these systems began with component-level improvements including nozzle droplet size and material use and management, and it has evolved to full system integration utilizing cameras and sensors for plant-specific application. In 1996, pulse-width modulations for agricultural spray modules were first explored for precise chemical application. Controlling nozzle flow reduced ramp up/down times leading to more accurate application. These systems were then integrated into commercial GPS-based vehicle spray systems, which reduced spray drift in sensitive geographic areas [32,33]. Since the original development of the systems, the technology has now expanded to utilize cameras and image analysis to include portable classification applications for plants and soil (pCAPS) [34]. Variations in these systems include multiple techniques, but most utilize image processing for irrigation management and chemical application. Cambra et al. utilized a drone equipped with an RGB camera to capture video and GPS points of weed locations on the field [35]. This information was then relayed to a fertilizer sprayer, which only applies chemicals on weed plants [35]. In 2020, the technology and approach were expanded to real-time classification and processing onboard the application equipment itself. This system utilizes an RGB camera mounted on the front of the application vehicle to capture images of crops and weeds. The raw images are then processed using computer vision to perform segmentation, feature extraction, and classification. The classification of the plant determines chemical actuation or fertilizer or herbicides [36]. These spray control systems use GPS, real time kinematic (RTK) positioning, and inertial measurement units for precise application and have substantially improved the efficiency of agricultural application and reduced driver workload [37,38]. Similarly, adapting this technology to automate brine application has the potential to significantly reduce driver workload and improve the consistency of brine application on routes. This consistency is particularly important not only for a single driver, but also for ensuring consistency between drivers, primarily along routes that may have multiple drivers.

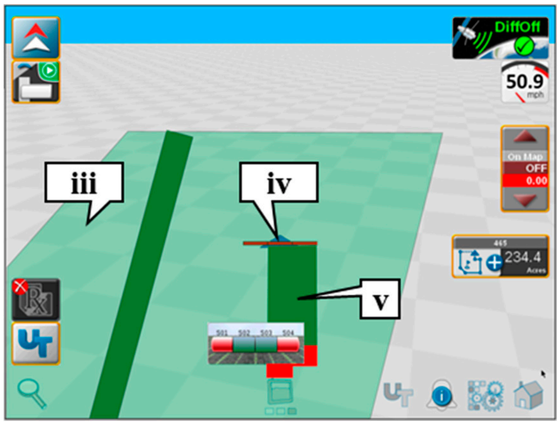
5. Objective and Scope

The objective of this study is to prototype and test the deployment of an automated liquid application system to reduce distracted driving and improve consistency. This study adapted precision agriculture equipment to automate brine application on select urban interstates for the 2022–2023 winter season. This study also quantified the number of driver distraction events associated with activating/deactivating brine switches on routes by storm and provided an estimate of the number of reduced distractions over the whole winter season.

6. Overview and Methodology

The development of automated brine began with the adaptation of a precision agriculture controller. Figure 5a shows the interior of the truck cab with callout i being the standard truck operation and perspective. The user interface controller, a global navigation satellite system (GNSS) antenna, solenoid control module, and wiring harness are four pieces of equipment from the agricultural industry required to automate the brining controls [39,40]. The user interface controller (callout ii in Figure 5a) is a Raven Viper 4, a 12.1-inch touch screen with the Raven Operating System installed. The GNSS antenna is a Raven 500S that has 114 channels, a 10 Hertz update rate, 3-channel satellite-based augmentation systems (SBAS) tracking, and it has 0.3 m horizontal accuracy with SBAS [41]. The standard brining equipment originally installed on the tanker by the Department of Transportation was integrated with the automated system components with minimal impact to the mechanisms, which includes the hydraulic wet-kit, brine pump, spray nozzles, and brine tank, which can be seen in Figure 2. The automated brine system added a controller in the cab of the truck near the operator, seen as callout ii. The operation of the automated brine tanker relies on pre-defined application zones for bridge decks/underpasses or perhaps the whole road surface for long segments in some cases. These zones are defined offline in a geographic information system (GIS) package to generate the geofence boundaries. In general, this can be performed with sufficient accuracy using Google Earth imagery.

(a)



(b)

Figure 5. Automated application controller interface. (**a**) View as brine operator. (**b**) Automated brine application controller.

The operating framework of the system begins with the definition of the application zone. After the application zones are created, they are sent to the controller either by plugging in a flash drive with the files and transferring them manually to the controller or by uploading the files remotely through the Raven Slingshot portal. Once the files are uploaded to the controller, the operator or manager can load the specific application file/zones and specify the rate of application (typically 50 gal/lane-mile). Before departing, the operator will set the tanker to be in "automatic mode". These geofenced application zones, as viewed on the controller screen, can be seen in Figure 5b as callout iii. The controller uses the GNSS antenna on the truck to determine if the vehicle is within an application zone or outside of it. Figure 5b callout iv shows the current location of the brine tanker which lies within an application zone. When the vehicle is in the application zone, the system begins applying the material out the back of the tanker. The application of brine can be observed trailing the vehicle in the spray zone on the controller screen as callout

v. While the vehicle is in the application zone, the controller will monitor overlap from a previous run and turn off the boom that overlaps previous applications. This prevents feature over/double application and preserves material. After loading the file containing the geofenced areas and selecting automatic mode, the driver does not need to interact with the controller other than to monitor the application. Due to the controller being controlled by a GNSS receiver, there is potential for a loss of signal, in adverse conditions, during which the operator will have to manually apply brine. During this study, there were no noticeable signal losses that impacted the automated brine application.

The cost for the automation equipment and installation is approximately USD 30,000 per fleet vehicle. This cost includes the sensors and controls, web portal subscription, installation, and training costs. The largest advantage of automating material application is reducing driver workload by allowing operators to focus on safely driving the route without the need to manually activate/deactivate a switch on the adjacent console (Figure 4b). This technology was first installed on one truck as a testbed and prototype. Once the controls were configured and concept-validated, Indiana DOT expanded the automated brine application to six additional trucks, and by the end of the 2022–2023 winter season, a total of seven trucks had the capability to apply brine automatically.

7. Impacts of Automation on Reducing Driver Workload

To automate the application process, brine application zones were created for bridge decks and underpasses statewide. The creation of the application zones was performed on ArcGIS for all Indiana interstates, which can be seen in Figure 6. The location of each bridge deck is color coded by the operating district it resides in. Across the interstate system, there were over 1300 bridge decks or underpasses, and, if an operator must turn the controls on and off, for just one pass on all of the interstates, they have to flip the switch 2600 times. If it is assumed that each interstate has four lanes (two lanes each direction), and the agency is brining all lanes, the operators must turn the controls on and off over 10,000 times in advance of one winter storm.

A more localized example on I-465 shows the impact on one driver. In the Indianapolis area (Greenfield District), there are bridge decks on average every 0.5 miles on I-465, resulting in approximately 100 application zones. Additionally, with 6–10 lanes on this route, an operator would have to manually activate the application 1200 times just to brine a minimum of three lanes in each direction. Figure 7 below shows all the application zones on I-465, with the interstate loop around Indianapolis having an average annual daily traffic count varying from 100,000 to 200,000 vehicles [42]. The implementation of this automated liquid brining system enhances overall safety by reducing driver workload and eliminating the 1200 times the driver must divert some attention to turning a switch on or off.

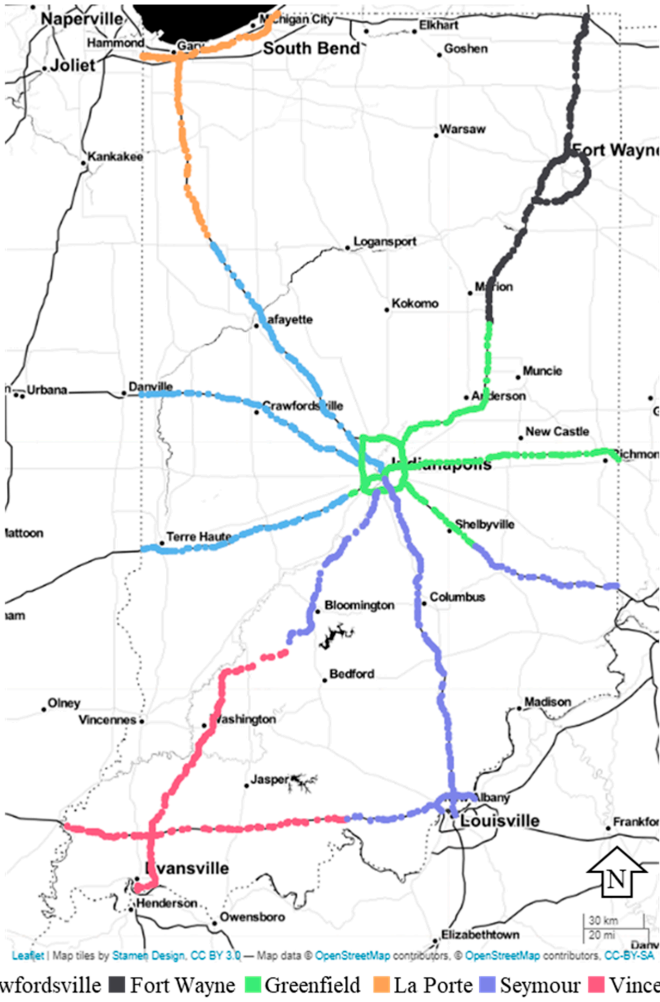


Figure 6. Location of 1339 Indiana interstate bridge decks and underpasses identified for spot pre-treatment.

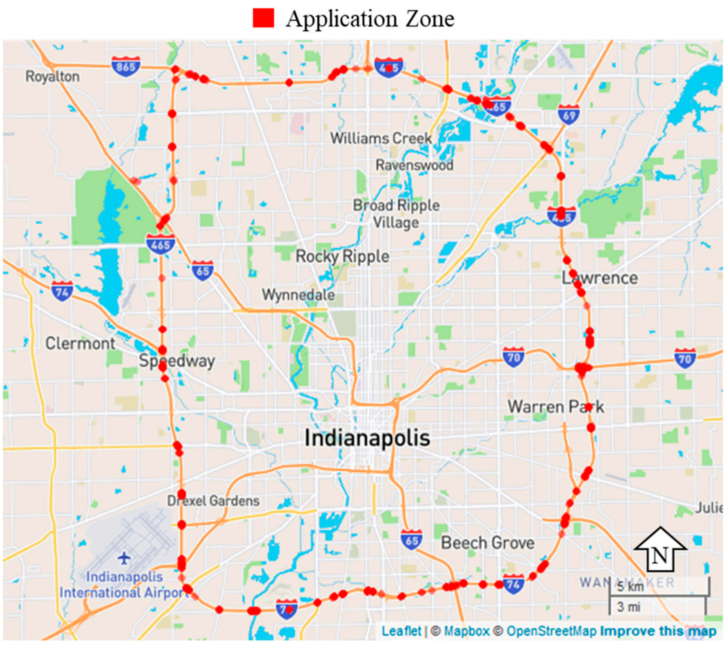


Figure 7. I-465: Location of 100 bridge decks and underpasses identified on I-465 for pre-treatment.

8. Summary Statistics from 2022–2023 Winter Season

8.1. Total Miles of Application

One of the advantages of the automated brining system is the ability to track and monitor the material application and its location. During the 2022–2023 winter season, a total of 3053 miles of brine was applied using this technology equipped on two tankers. Additional tankers were finished at the end of the winter season and were not utilized in this analysis except for testing. Application was focused on urban interstates to utilize the system in the most challenging conditions. Figure 8 shows equal application per direction on each route, which is expected, with the exception of I-465. On I-465, due to the magnitude of the roadway, additional brining vehicles not equipped with the automated brine controller assisted with brining, reducing the number of application miles on the I-465 inner loop (callout i).

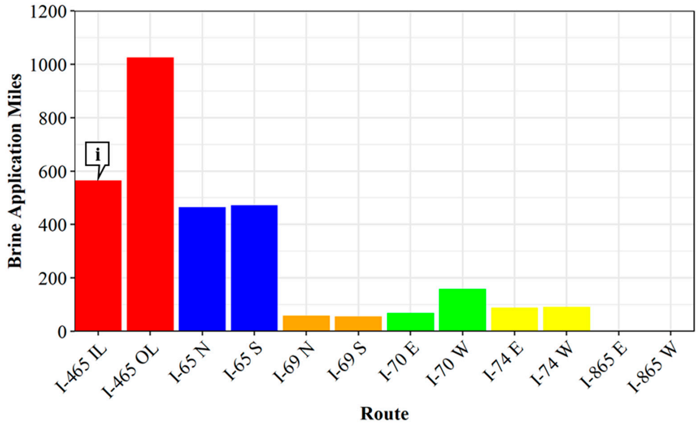


Figure 8. Total brine application miles for winter 2022–2023 season.

8.2. Safety Improvements

The automated brining system was used for one truck for most of the season and an additional truck came online on 10 January 2023. The number of switch activations prevented by date is observed in Figure 9. Due to a mild winter, the brine application trucks were only deployed 18 days this winter season on six interstate routes around Indianapolis. The automated brining controller eliminated 6776 distracted driving events for the operators, an average of 376 events per application day. The adaptation of this system will improve winter operations for agencies, operators, and road users by ensuring consistency and improving safety for all.

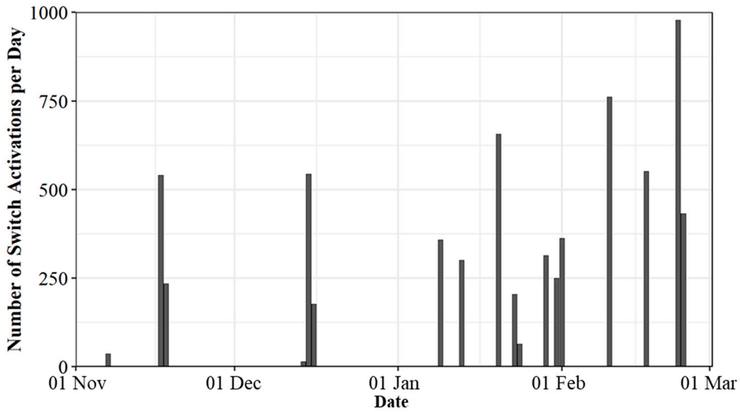


Figure 9. Number of on/off switch activations by several pre-treatment trucks during the 2022–2023 season.

9. Conclusions and Future Scope

This paper describes the integration of precision agricultural spraying technology into Indiana Department of Transportation trucks that apply pre-treatment chemicals with the goal of reducing driver workload and distractions. Geofences were defined for over 1300 bridge decks and underpasses across 2500 miles of interstate so that brine pre-treatment could be automated and applied consistently with no additional driver workload of turning solenoid control switches on and off (Figure 5). A total of 3000 miles of brine was applied during the winter season of 2022–2023 using this technology (Figure 8). The results showed that this system eliminated more than 6700 distracted driving events for the operators during the course of a winter season, which averages nearly 376 events per application day (Figure 9). The early deployments were focused on high-volume interstate routes in central Indiana (I-65 and I-465) but have been since scaled to a total of seven 5500-gallon brine tankers.

A lower bound on the number of manual switch actuations on a statewide pre-treatment event for bridge decks and underpasses is approximately 10,000 actuations, assuming two directions and an average number of lanes of four. Reducing driver workload and potential distractions are critical in improving safety during winter operations and can be expanded to other maintenance work. Additionally, the precise application of materials not only provides environmental benefits but also reduces application waste, which in turn reduces overall operating costs and time. The framework and techniques presented in this study enhance safety, reduce driver workload, and ensure the consistent application of brine in designated areas.

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