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# Design and Feasibility of an Impact-Based Odor Control System

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**Abstract**

Legislation and rural communities are increasingly requesting reductions in odor emitted from swine production facilities. If odor is regarded solely as a nuisance, and not an environmental hazard (as in this research), such that the objective of treating ventilation exhaust air is to prevent odor from impacting nearby receptors, it is unnecessary to treat exhaust air when dispersed odor is not identifiable. This approach maximizes odor reduction potential when most needed, with economic benefit through decreased energy and resource usage by simply operating the mitigation device for less time. The objectives of this article were: to develop an on-off, real-time control system for on-farm odor mitigation devices and provide insight on the potential reduction in operation time of any odor mitigation strategy for climatic variability. The Impact Based Odor Control System (IBOCS) monitors wind speed, wind direction, and insolation to determine atmospheric stability, and utilizes location of nearby receptors relative to a facility to conclude if exhaust air requires treatment. A prototype of IBOCS was developed and consisted of an Arduino to execute the control algorithm and manage sensor measurements, receptor directional locations, and device activation or deactivation. The user interface included an eight-direction toggle switch indicator (i.e., receptor directional location), power switch, automatic/manual switch to override IBOCS, and additional tactile inputs for manual control. The feasibility of implementing IBOCS was evaluated at five simulated locations (MN, IA, MO, IN, and NC) in the United States by computing the reduction in annual mitigation device operation based on IBOCS logic from Typical Meteorological Year 3 data sets. Regardless of receptor location relative to a simulated facility site, IBOCS logic estimated annual mitigation technology operation to range from 64.4% (NC) to 71.4% (IN). Further, the minimum estimated annual operation ranged from 14.2% (IA) to 27.9% (MO) with only one receptor present. The overall goal of IBOCS is to reduce the impact of dispersed odor while concurrently decreasing operational expenses for expensive mitigation technologies.

**Keywords**

Dispersion, Emissions, Mitigation, Swine, Ventilation

**Disciplines**

Agriculture | Bioresource and Agricultural Engineering

**Comments**

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# DESIGN AND FEASIBILITY OF AN IMPACT-BASED ODOR CONTROL SYSTEM

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**ABSTRACT.** *Legislation and rural communities are increasingly requesting reductions in odor emitted from swine production facilities. If odor is regarded solely as a nuisance, and not an environmental hazard (as in this research), such that the objective of treating ventilation exhaust air is to prevent odor from impacting nearby receptors, it is unnecessary to treat exhaust air when dispersed odor is not identifiable. This approach maximizes odor reduction potential when most needed, with economic benefit through decreased energy and resource usage by simply operating the mitigation device for less time. The objectives of this article were: to develop an on-off, real-time control system for on-farm odor mitigation devices and provide insight on the potential reduction in operation time of any odor mitigation strategy for climatic variability. The Impact Based Odor Control System (IBOCS) monitors wind speed, wind direction, and insolation to determine atmospheric stability, and utilizes location of nearby receptors relative to a facility to conclude if exhaust air requires treatment. A prototype of IBOCS was developed and consisted of an Arduino to execute the control algorithm and manage sensor measurements, receptor directional locations, and device activation or deactivation. The user interface included an eight-direction toggle switch indicator (i.e., receptor directional location), power switch, automatic/manual switch to override IBOCS, and additional tactile inputs for manual control. The feasibility of implementing IBOCS was evaluated at five simulated locations (MN, IA, MO, IN, and NC) in the United States by computing the reduction in annual mitigation device operation based on IBOCS logic from Typical Meteorological Year 3 data sets. Regardless of receptor location relative to a simulated facility site, IBOCS logic estimated annual mitigation technology operation to range from 64.4% (NC) to 71.4% (IN). Further, the minimum estimated annual operation ranged from 14.2% (IA) to 27.9% (MO) with only one receptor present. The overall goal of IBOCS is to reduce the impact of dispersed odor while concurrently decreasing operational expenses for expensive mitigation technologies.*

***Keywords.*** *Dispersion, Emissions, Mitigation, Swine, Ventilation.*

Odor dispersion from swine facilities has experienced scrutiny from rural communities and regulators. Swine odors produced from the breakdown of manure by microorganisms are dispersed during land application of slurry, manure storage facilities, and building ventilation exhaust air (Janni, 2010; Liu et al., 2014). Typically, exhaust air from swine facilities is untreated, resulting in odors containing hundreds of chemicals, including volatile organic compounds, ammonia, hydrogen sulfide, and many other substances found at low concentrations (Zhu, 2000; Zhang et al., 2002; Millner, 2009), to be potentially detected by the human olfactory response. Odors can become a nuisance to nearby receptors (e.g., neighbors, communities, people outside, etc.) and with more potential regulation on odor and gaseous emissions levels (Honeyman, 1996; Vukina et al., 1996; Jacobson et al., 1999; Henry et al., 2007; Stowell et al., 2007; Ferguson et al., 2010; Liu et al., 2014), there is a requisite need for developing and implementing odor mitigation technologies that reduce the impact on surrounding receptors and are cost effective for swine producers to implement.

If odor is regarded solely as a nuisance, and not an environmental hazard, such that the objective of treating exhaust air is to reduce the odor impact for nearby receptors, it is often unnecessary to treat all exhaust air, all of the time. Many factors such as atmospheric stability, which is a function of wind direction, wind speed, and insolation (solar radiation), in conjunction with receptor relative location and distance from a facility influence if dispersed odor is identifiable. These factors have been incorporated into several odor dispersion simulation models for siting new facilities (Cimorelli et al., 2005; Jacobson et al., 2005; Hoff et al., 2008; Hoff et al., 2008). If dispersed odor is not identifiable; hence, not a potential nuisance to nearby receptors, operation of a mitigation technology could be substantially reduced by either bypassing or powering off the device. This on-off control approach maximizes odor reduction potential when most needed, with economic benefit through decreased energy and resource usage by simply operating the mitigation

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device for less time. A control system is needed to assess atmospheric stability, determine potential impact region(s) downwind of a facility, and automatically deactivate or activate a mitigation device when needed.

Several methods have been developed to mitigate odors from swine facility exhaust air such as biofilters, wet scrubbers, oil spraying, ultraviolet light, electrostatic precipitation, which are thoroughly discussed in literature [Liu et al., 2014; Air Management Practices Assessment Tool (AMPAT), 2015]. Operation of these devices is typically continuous and lack any control mechanism. Operating costs and energy usage varies greatly among technologies, ranging from \$0.05~\$0.5 per head produced (biofilters) to ~\$2 per head produced (wet scrubbers). There are considerable opportunities to decrease operating costs though intermittent operation; however, this technique may affect device longevity. For example, frequent power cycling to an actuator, fan, or light bulb may cause devices to wear or need replacement more often. Biofilters in particular may require a minimum flow and moisture to sustain the microbial communities and remain effective (Li et al., 1996). Similarly, for devices utilizing pumps, check valves must be installed in appropriate locations to avoid running a pump dry or repeatedly priming a pump.

This research views odor as a nuisance; therefore, reducing identification by nearby receptors is most critical. The Impact Based Odor Control System (IBOCS) was developed to cost effectively operate mitigation devices used in swine production systems where odor control is limited to events that would most likely impact surrounding receptors. IBOCS monitors atmospheric stability and utilizes the input of nearby receptor(s) direction relative to a facility to determine if odorous exhaust air needs to be attenuated. To achieve these goals, the objectives were to: (1) instrument and develop a control system for controlling on-farm mitigation devices, and (2) provide insight on the potential reduction in operation time of any odor mitigation strategy for climatic variability.

# MATERIALS AND METHODS

## ATMOSPHERIC STABILITY

The rise of gas plumes and subsequent dispersion of gas plumes are substantially influenced by the amount of turbulence in the ambient air (Beychok, 1994). The Pasquill Stability Classes (PSCs) categorize the amount of turbulence in the atmosphere into finite levels based on wind speed and insolation. Stability classes (table 1) are composed of classes: A (most unstable or most turbulent), B (unstable), C (slightly unstable), D (neutral), E (slightly stable), and F (most stable or least turbulent). Odor plumes have a higher likelihood to remain near the ground in a stable atmosphere (defined as class D through F) and subsequently, are detected by nearby downwind receptors; thus, odor mitigation may be required. Alternatively, an unstable atmosphere (defined as class A through C) implies odor plumes rise and mix vertically close to the odor emission source (low lateral dispersion). Odor exhausted from swine facilities into an unstable atmosphere disperses before reaching nearby receptors and odor mitigation is deactivated, bypassed, or powered off.

**Table 1. Meteorological conditions that define the Pasquill Stability Classes (Beychok, 1994).**

| Surface Wind Speed, m s$^{-1}$ (mph) | Day-Time Insolation | | | Night-Time Cloud Cover[a] | |
|---|---|---|---|---|---|
| | Strong[b] | Moderate[c] | Slight[d][e] | > 4/8 Cloud | < 3/8 Cloud |
| < 2 (4.5) | A | A-B | B | - | - |
| 2-3 (4.5-6.7) | A-B | B | C | E | F |
| 3-5 (6.7-11.2) | B | B-C | C | D | E |
| 5-6 (11.2-13.4) | C | C-D | D | D | D |
| > 6 (13.4) | C | C | D | D | D |

[a] Neutral class D applies to heavy overcast skies, day or night.
[b] > 598.3 W m$^{-2}$
[c] 301.3 - 598.3 W m$^{-2}$
[d] < 301.3 W m$^{-2}$
[e] The shaded region indicates when a mitigation device is operational and corresponds to equations 1, 2, and 3.

## EQUIPMENT AND SENSORS

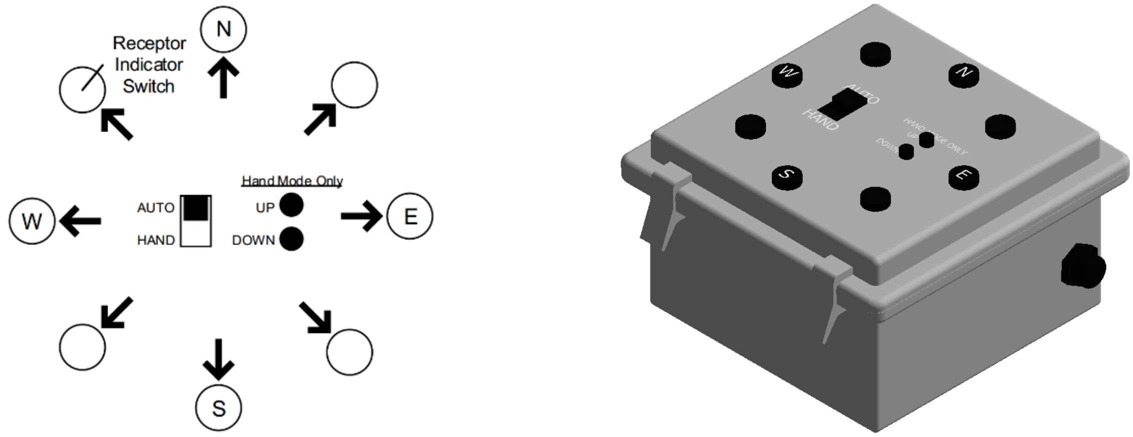
A prototype of IBOCS was developed to establish hardware requirements and demonstrate control system functionality. The control system algorithm was programmed using the integrated development environment for the microprocessor (Mega 2560, Arduino LLC, Italy). Data were stored on a removable flash memory via a datalogger (SD card shield V4.0, Seed Development Limited, Shenzhen, China). Due to potential lack of computers or internet access at swine production facilities, a real-time clock (RTC Module, Freetronics Pty Ltd., Crodon South, Australia) was used to timestamp recorded data.

IBOCS required sensors to measure wind direction, wind speed, and insolation. Minimum sensor criteria was established to be a wind vane with at least 5° of measurement resolution and threshold wind speed of less than 2 m s$^{-1}$. The anemometer should have a threshold that is the same as the wind vane. A horizontally mounted pyranometer for total (global) direct and diffuse solar radiation measurement should be used to determine insolation. The choice of sensors is determined by the end user.

Input of receptors relative to a facility was indicated by an eight-position switchboard (fig. 1) corresponding to eight compass locations (every 45°). The presence of a receptor was indicated by depressing the Receptor Directional Location (RDL) switch (fig. 1). Two switches may be used to indicate a receptor located between two directional positions (e.g., a receptor located at 112.5°, from North, switches located at 90° and 135° may be depressed). Other features included hand (manual) or automatic (auto) operation mode in the event a device required maintenance. Once in hand operation mode, momentary switches could be used for manual control over the device, such as raising or lowering an actuator.

## CONTROL LOGIC

The algorithm determined the mean insolation, wind speed, and wind direction every 15 min from measurements made once a minute (n = 15), and stored identified




(a) (b)

**Figure 1. (a) User interface for receptor directional indicator for IBOCS. Eight receptors are possible and located every 45° around a facility. (b) Three-dimensional drawing of IBOCS prototype.**

receptors (fig. 2). The software selectable control decision frequency was chosen to satisfy the following: reducing the likelihood of identifiable odors from impacting surrounding receptors, respond quickly to changing atmospheric conditions, and to not prematurely degrade equipment.

A mitigation technology was determined to be activated for classes D through F (encompassed by eqs. 1, 2, and 3) and deactivated, for classes A through C (table 1), based on work completed by Hoff et al. (2008a), Hoff et al. (2008b), and Jacobson et al. (2005).

$$\mathrm{WS} \geq 5.0 \ \& \ \mathrm{GHI} \leq 301.3 \ \& \ \mathrm{RDL} - 22.5° \leq \mathrm{WD} \leq \mathrm{RDL} + 22.5° \quad (1)$$

$$\mathrm{GHI} \leq 100.0 \ \& \ \mathrm{WS} \geq 2.0 \ \& \ \mathrm{RDL} - 22.5° \leq \mathrm{WD} \leq \mathrm{RDL} + 22.5° \quad (2)$$

$$\mathrm{GHI} \leq 100.0 \ \& \ \mathrm{WS} < 2.0 \quad (3)$$

where
WS = mean wind speed (m $s^{-1}$)
GHI = mean global horizontal insolation (W $m^{-2}$)
RDL = receptor directional location (°)
WD = mean wind direction (°)

Equation 1 was valid only during the daytime (i.e., $100 \leq \mathrm{GHI} \leq 301.3$ W $m^{-2}$) and when average wind direction was within the ±22.5° region of the RDL. This region was larger than the ±10° utilized in other odor siting models (Hoff et al., 2008a), in order to ensure all potential receptor locations were covered by the control logic. Albeit, if the standard deviation of wind direction was greater than 22.5° and RDLs were identified adjacent to the mean wind direction, the mitigation device was activated. If equation 1 was satisfied and wind direction was such that a receptor would not be impacted, the mitigation device was deactivated (fig. 2). Equations 2 and 3 included classes D through F during nighttime (i.e., $\mathrm{GHI} \leq 100.0$ W $m^{-2}$) and were achieved regardless of wind speed (table 1). However, the lowest wind speed category for a defined PSC was: < 2 m $s^{-1}$ (table 1); therefore, 2 m $s^{-1}$ was used as the minimum wind speed that would disperse odor in the direction of a downwind recipient. Hence, input of RDL was used for wind speeds greater than 2 m $s^{-1}$ (eqs. 1 and 2). For wind speeds less than 2 m $s^{-1}$, reliable measurement of wind direction may not be possible (sensor threshold will vary based on technology) and odor was assumed to disperse omnidirectionally from the facility. When below the wind vane or anemometer sensor threshold, assumed to be 2 m $s^{-1}$, wind speed was recorded as 0 m $s^{-1}$, and wind direction recorded as 0° (North is 360°). Equation 2 was valid at night when the wind was strong enough to disperse odor, such that a downwind receptor would be impacted (similar to eq. 1); hence, the RDL must be within the ±22.5° region. Conversely, equation 3 corresponded to nighttime only, during light breeze conditions; hence, WD and subsequently, RDL were ignored, and the mitigation technology was activated, as long as a receptor was indicated to be present anywhere on the receptor indicator switchboard.

Input of receptor distance from the facility was not included in the control logic. While this was an important factor in odor identification, the user's discretion must be used to determine if the receptors distance from the facility was such that the receptor would be impacted. Siting tools and odor dispersion models could be used to assist with this decision.

## FEASIBILITY EVALUATION

The dynamic and diverse nature of atmospheric conditions, coupled with the geographical and temporal dependence, led to the evaluation of IBOCS using Typical Meteorological Year 3 (TMY3; Wilcox and Marion, 2008) data sets at five different locations (Mankato, Minn.; Boone, Iowa; Jefferson City, Mo.; Grissom, Ind.; and Fayetteville, N.C.) in the United States (fig. 3). Rather than use experimentally obtained data, TMY3 data sets are intended for design evaluations (such as this one) and solely collecting data at 1 min intervals in one location would not provide adequate insight to the potential reduction in mitigation technology operation in different climatic regions where odor is often a nuisance. TMY3 data sets are derived from historical data in hourly intervals for one year; hence, this method will be overestimating mitigation technology operation time compared to the recommended aforementioned control decision frequency

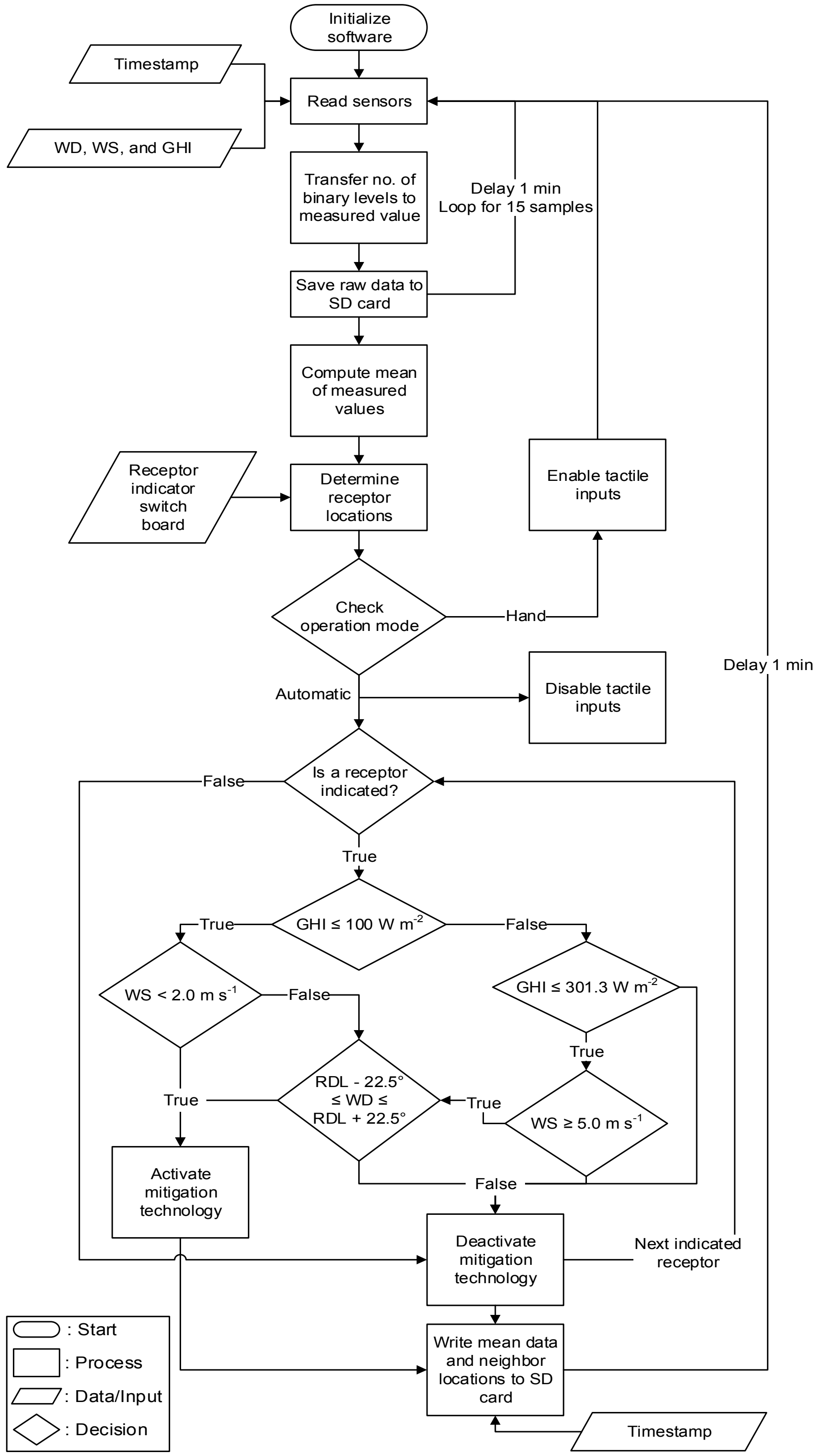



**Figure 2. Pseudo control logic algorithm for IBOCS.**

of every 15 min. Frequency of mitigation device operation was evaluated hourly for one year based on the criteria in equations 1, 2, and 3, with global horizontal insolation, wind speed, and wind direction obtained from the TMY3 data sets. In addition, percent annual operation was analyzed by PSC (table 1), RDL (i.e., wind direction ±22.5° of the eight compass positions and calm), and meteorological season. In addition, a sensitivity analysis was performed to simulate the potential reduction in annual cost to operate a mitigation device for different mitigation device operating costs (cost per head produced) if IBOCS was implemented. TMY3 data were imported and processed using Matlab (R2015b, The MathWorks Inc., Natick, Mass.).

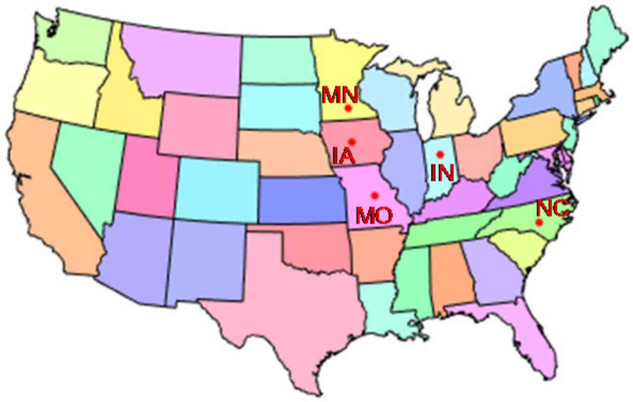



**Figure 3. Simulated facility locations at Mankato, Minn.; Boone, Iowa; Jefferson City, Mo.; Grissom, Ind.; and Fayetteville, N.C. identified by their state abbreviation.**

## RESULTS AND DISCUSSIONS

Regardless of receptor location relative to a simulated facility site, IBOCS criteria estimated annual mitigation device operation (fig. 4) to range from 64.4% (NC) to 71.4% (IN); thus, an approximate 29% to 36% reduction compared to continuous operation. This was attributed to unstable atmospheric conditions as indicated by PSCs that cause rapid vertical mixing of odor plumes near the source (class A through class C); hence, no mitigation required. Lower overall wind speed regions (MO and NC) showed less annual operation (fig. 4) due to the smaller contribution of equations 1 and 2 to the total annual operation; however, in those regions where wind speed decreases at night, a mitigation device will be activated a greater percentage of the year. The higher wind speed regions have greater opportunity to reduce mitigation device operation because if a receptor is not positioned downwind, there is no need to mitigate. Addition of receptor location relative to the simulated facility, plus wind direction would further decrease mitigation device operation time.

Analysis of PSC frequency, regardless of relative receptor location to the simulated facility site, showed nighttime (classes D-F) to require mitigation operation the most frequent among simulated facilities (fig. 5). This result suggests control decisions with illuminance, rather than insolation may be incorporated. For example, insolation could be directly replaced with illuminance in equations 1, 2, and 3, using a correlation found between the two. Further, since commercially available pyranometers are more expensive than visible light sensors (e.g., cadmium sulfide), this could decrease the capital cost of IBOCS. Another alternative could be to utilize equations of time and solar time equations (ASHRAE, 2013) to replace the pyranometer or visible light sensor, and further reduce the capital cost of IBOCS. Additional programming and input of the facility's geographical location (i.e., latitude and longitude) would be required.

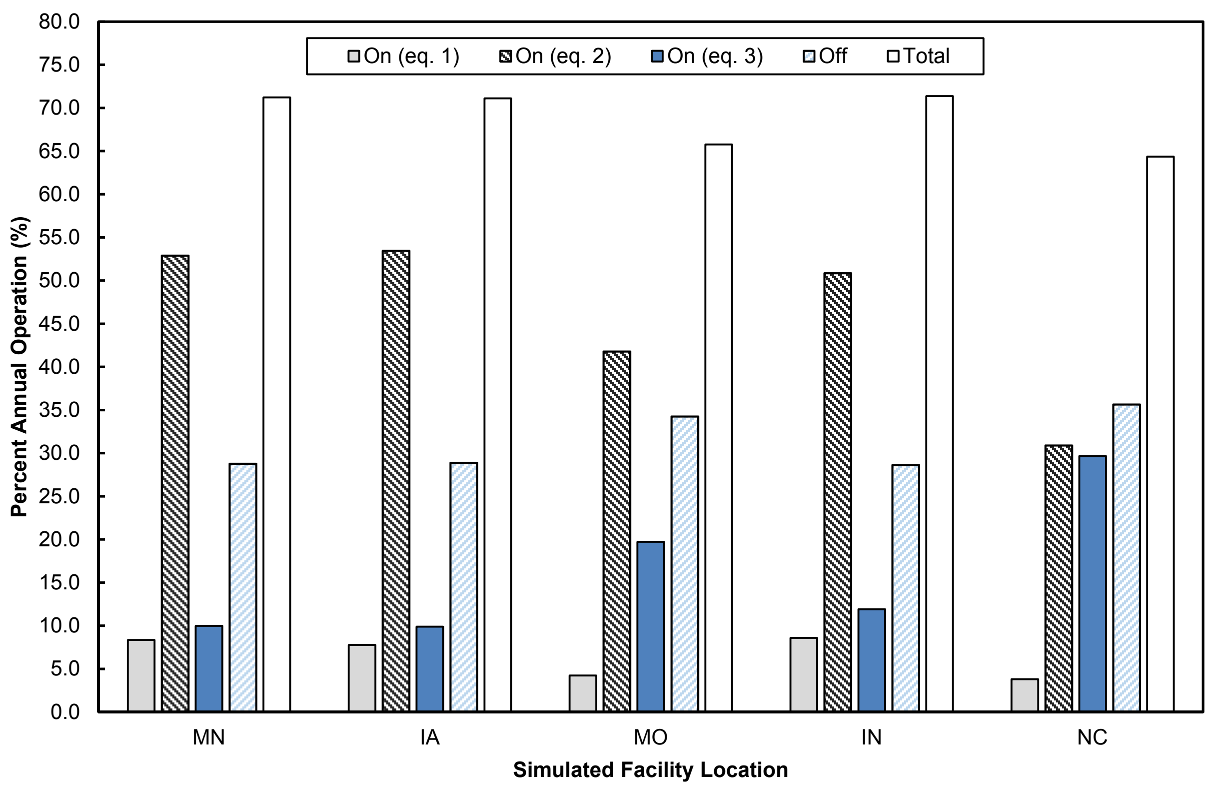



**Figure 4. At five simulated facilities located in the United States, IBOCS logic decreased annual mitigation operation regardless of receptor location relative to the facility. Mitigation was operational for a larger percentage of the year during night (eqs. 2 and 3) compared to daytime (eq. 1).**

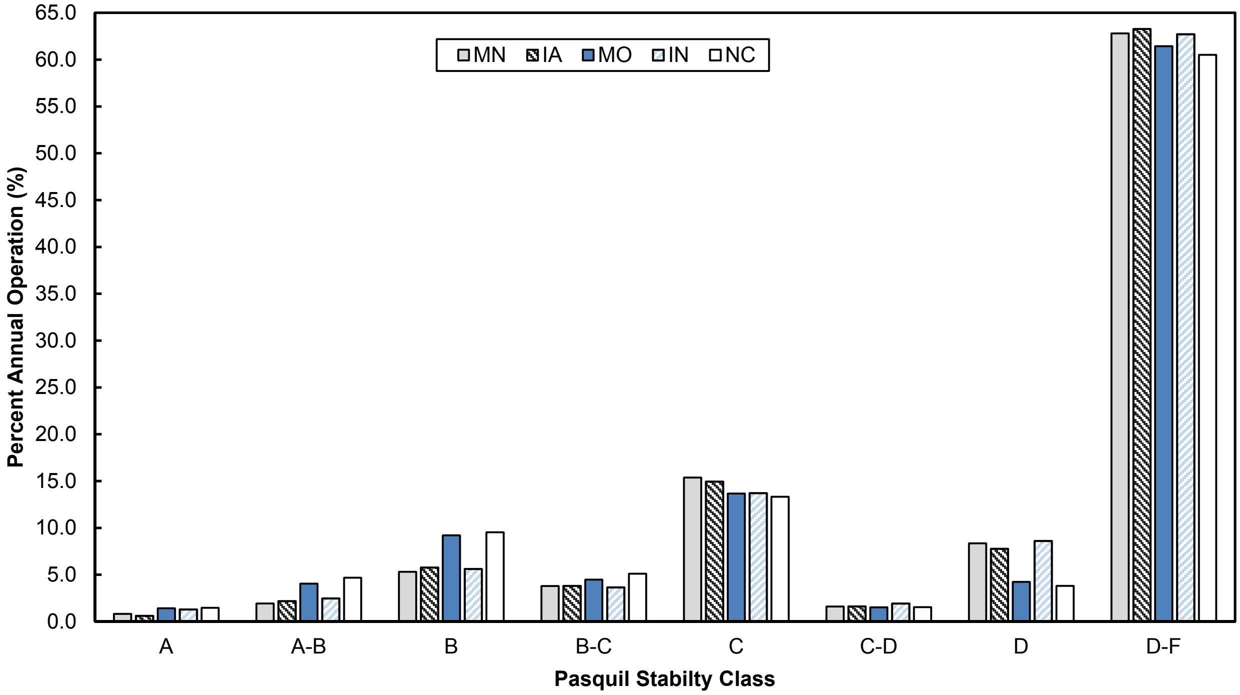



**Figure 5. Regardless of receptor location relative to the simulated facility site, the most frequently estimated Pasquil Stability Class was during nighttime.**

Although the decision to operate a mitigation device for Class C was excluded, a more conservative approach could be to integrate mitigation device operation for Class C into the control logic (eq. 4). In the event Class C is included, annual mitigation operation is estimated to range from 79.2% (NC) to 88.2% (NC). This is an additional 14.9% (NC) to 16.9% (MN) increase in operation, compared to when Class C was excluded from the control logic (fig. 4).

$$(WS \geq 5.0 \ \& \ GHI \geq 301.3 \mid WS \geq 2.0 \ \& \ GHI \leq 301.3)$$
$$\& \ RDL - 22.5° \leq WD \leq RDL + 22.5° \quad (4)$$

where

WS = mean wind speed (m $s^{-1}$)
GHI = mean global horizontal insolation (W $m^{-2}$)
RDL = receptor directional location (°)
WD = mean wind direction (°)

Estimated mitigation device operation analyzed by meteorological season (fig. 6) showed operation during winter to be more prevalent, with an average (±standard deviation) annual operation of 38.3% ±2.2% across the five simulated facility locations. Mean annual operation during spring (11.7% ±0.75%) and fall (13.7% ±0.5%) were similar across simulated facilities. Operation during the summer was the lowest at 5.2% ±0.3%. Receptor identification will most likely be more common during the spring, summer, and fall seasons as people tend to be traveling and outdoors; however, these three seasons combine for just 44% of the mean percent annual operation across simulated facilities. If winter was excluded, annual mitigation device operation could range from 28.9% (MO) to 32.1% (IA).

Annual estimated mitigation device operation could be further reduced if at least one receptor was indicated to be present (fig. 7). For example, if only one receptor was present, the minimum annual (including winter) operation ranged from 14.2% (located SE of simulated facility; IA) to 27.9% (located E of simulated facility; MO). This difference was attributed to the greater frequency of low wind speeds in MO compared to IA, in which the mitigation device is active regardless of receptor location and with one receptor present. Maximum annual (including winter) operation ranged from 37.9% (located E of simulated facility; MO) to 56.9% (located N of simulated facility; IA). If winter was excluded, the minimum annual operation ranged from 1.5% (located SW of simulated facility; IA) to 6.8% (located SW of simulated facility; MO). Maximum annual operation with winter excluded for one Receptor Directional Location (RDL) present ranged from 4.5% (located SW of simulated facility; IN) to 7.4% (located E of simulated facility; MO). There are many possible combinations of facility geographical location, number of receptors, and their location relative to a facility; hence, this analysis can provide insight to some potential annual operation times (direct cost saving to producer) for different configurations. If a siting model was not utilized or if legislation requires, this analysis could be used to estimate conceivable costs and operation frequency for potential mitigation technologies with and without IBOCS. More accurate wind direction sensors, such as sonic anemometers, could be utilized and feature low thresholds (i.e., typically < 0.1 m $s^{-1}$) and high wind direction resolution at low wind speeds. This technology could be used to reduce the nominal threshold value of 2 m $s^{-1}$ in

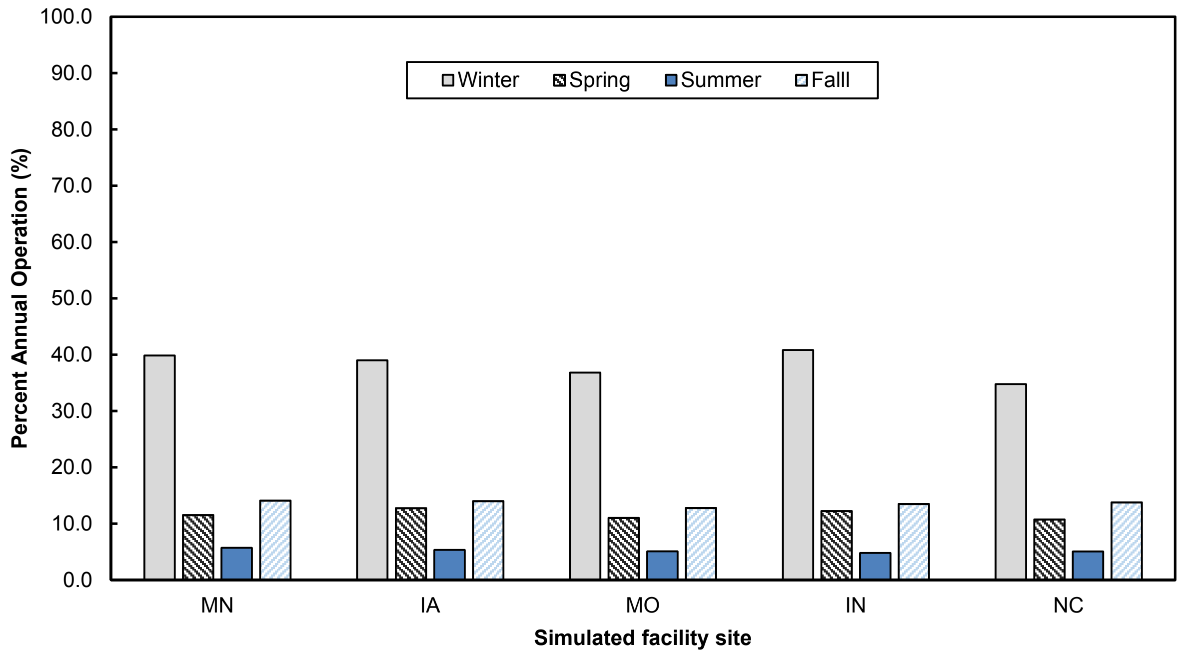



**Figure 6. Regardless of receptor location relative to the simulated facility site, winter was estimated to require to the most mitigation device operation.**

equations 2 and 3; however, this technology is considerably more expensive than mechanical wind vanes and 3-cup anemometers. By reducing the threshold in equations 2 and 3, mitigation device operation could be further reduced by including the RDL in the criteria.

The sensitivity analysis results showed that for higher mitigation device operating costs, a reduction in annual mitigation device operation with IBOCS logic implemented, substantially reduced annual operating costs (fig. 8). For mitigation devices with lower operating costs, a

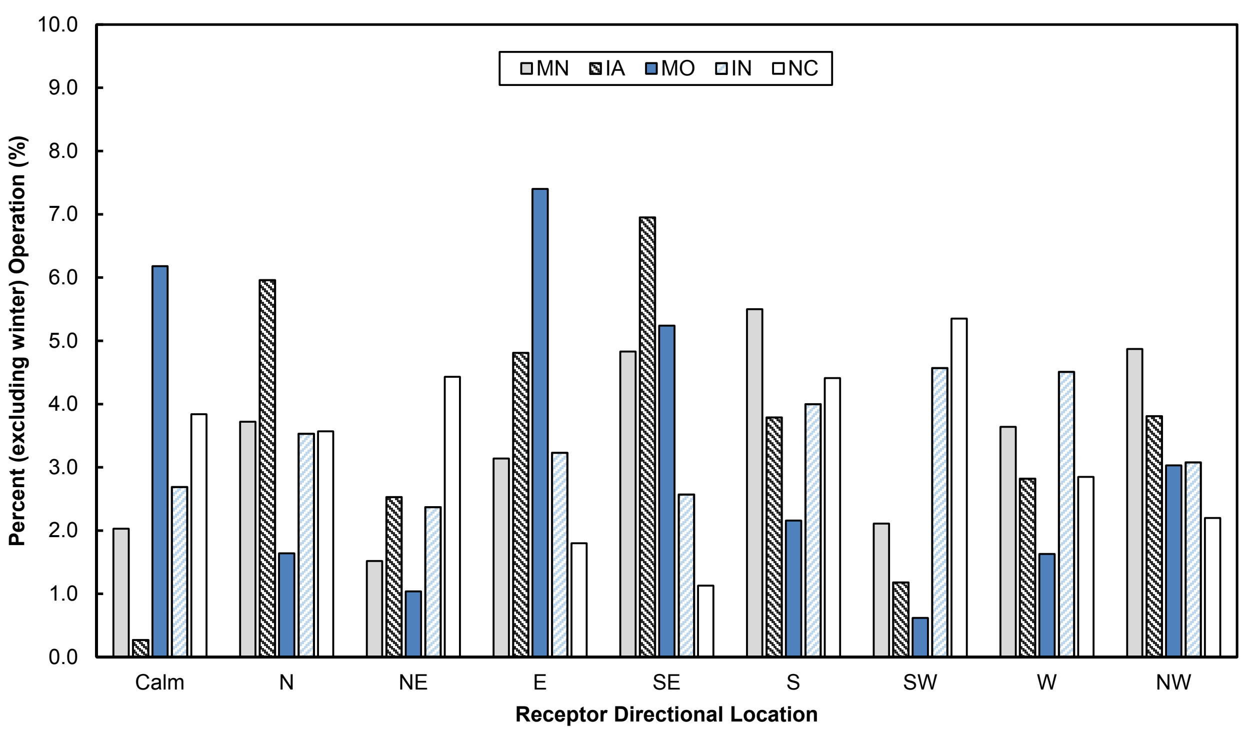



**Figure 7. Addition of wind direction further reduced annual (excluding winter) mitigation technology operation and could be used to determine conceivable costs and operation frequency for potential mitigation technologies with or without IBOCS. Calm is specified from the TMY3 data sets and has an undefined wind speed threshold (Wilcox and Marion, 2008).**

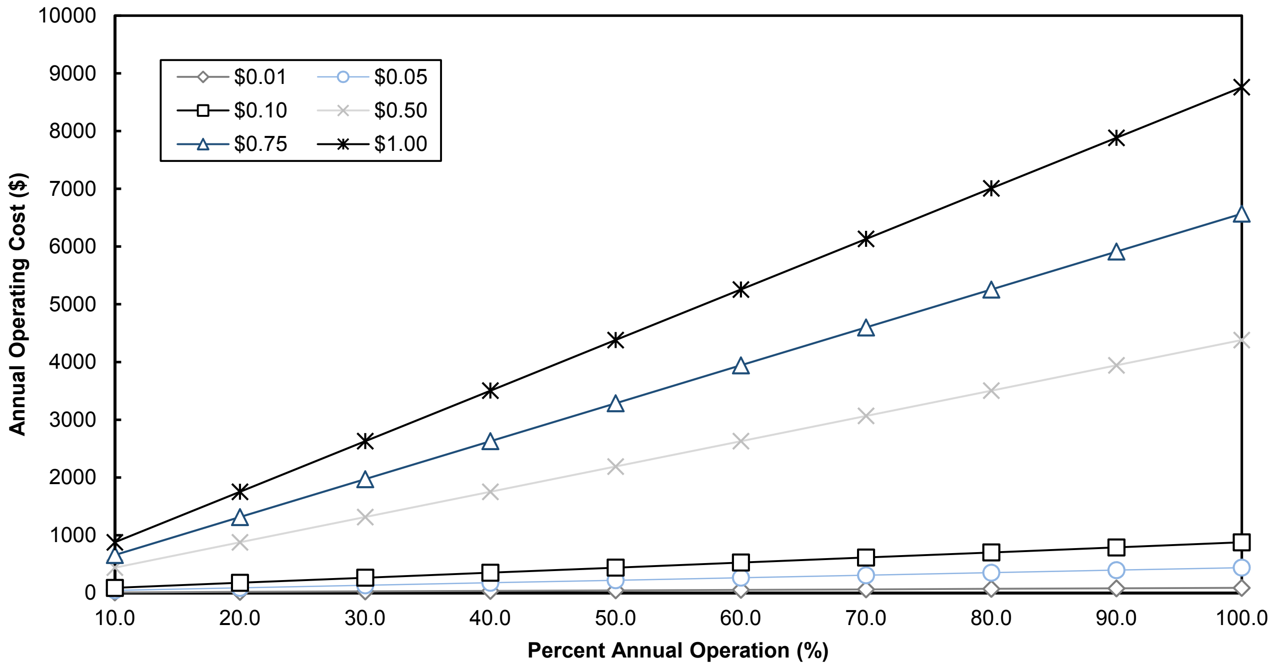



**Figure 8. Sensitivity analysis results showed a reduction in annual mitigation device operation substantially reduced annual operating costs for more expensive mitigation technologies.**

reduction in operation time had a reduced impact on annual operating costs. For example, a 30% reduction in annual mitigation device operation for a technology that cost $1 per head produced to operate, could reduce annual operating costs by approximately $2600 (fig. 8). Whereas, compared to a technology that cost $0.01 per head produced to operate, only about $26 $yr^{-1}$ could be saved (fig. 8). Further, a 60% reduction in annual mitigation device operation for a technology that cost $1 per head produced to operate, could reduce annual operating costs by approximately $5200. IBOCS may not offer a considerable reduction in annual operating costs for mitigation devices that are inexpensive to operate, but technologies that cost more to operate, IBOCS could provide large annual economic savings.

# Conclusions

Odor is a growing issue in the swine industry and, when considered a nuisance, requires mitigation to decrease identification by surrounding receptors. An Impact Based Odor Control System (IBOCS) was developed to cost effectively operate odor mitigation devices where, odor control is limited to events that would most likely impact surrounding receptors. An IBOCS prototype was created to monitor key parameters of atmospheric stability and utilize the input of nearby receptors directional location relative to a facility to determine if exhaust air required odor attenuation. The feasibility of this design and control logic were evaluated using hourly Typical Meteorological Year 3 (TMY3) data sets for five different locations (Mankato, Minn.; Boone, Iowa; Jefferson City, Mo.; Grissom, Ind.; and Fayetteville, N.C.) in the United States. Regardless of receptor location relative to a simulated facility site, IBOCS criteria decreased annual mitigation device operation by an estimated range from 64.4% (NC) to 71.4% (IN). Further, the minimum estimated annual operation ranged from 14.2% (IA) to 27.9% (MO) with only one receptor present.

Methods commonly used by siting models for new facility construction were adapted and implemented in a real-time monitoring and control system. IBOCS logic and hardware can be easily and readily implemented on a variety of on-off odor mitigation devices. Further work on the effect of on-off controlled equipment longevity is needed. IBOCS provides a real time and cost effective method to control odor mitigation devices while positively benefiting surrounding receptors. This analysis shows the feasibility and potential cost saving that will lead to informed decisions on implementing mitigation technologies.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