# Multi-year Operational Minimization Study in WV: Potential Novel Strategy to Reducing Bat Fatalities at Wind Turbines

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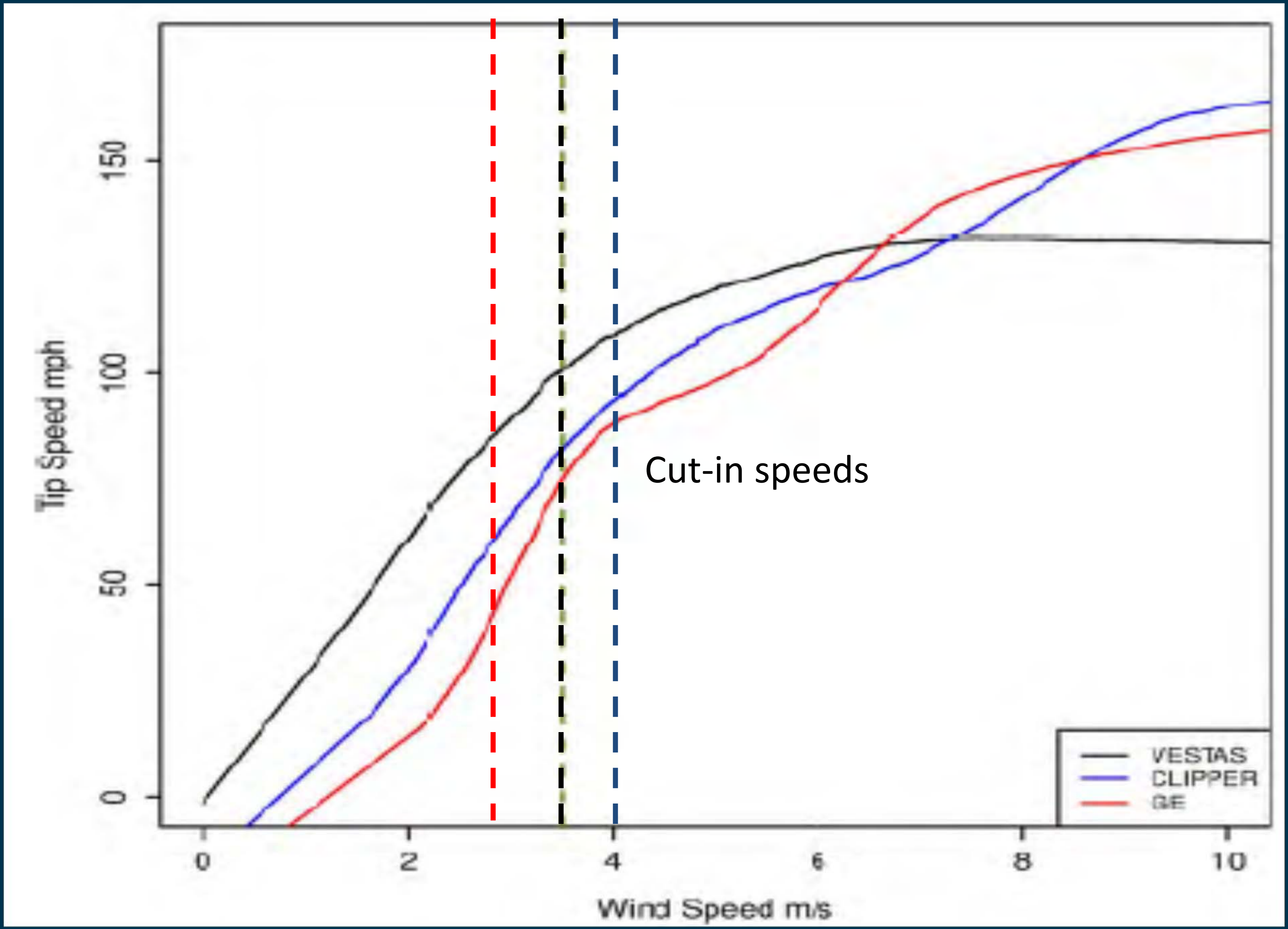
# Operational Minimization

- Bat fatalities are highest
  - Moving blades
  - Low wind conditions
- Lethal tip-speed?
- Variety of ways to change turbine operation

# General Turbine Operations

- Turbine start-up speed - speed at which rotor and blade assembly begins to rotate
- Cut-in speed – minimum wind speed when turbines will generate useable power (e.g. 3-4 m/s)
- Rated speed – minimum wind speed when turbine will generate its designated rated power (e.g. 1.5 mw)

# General Turbine Operations



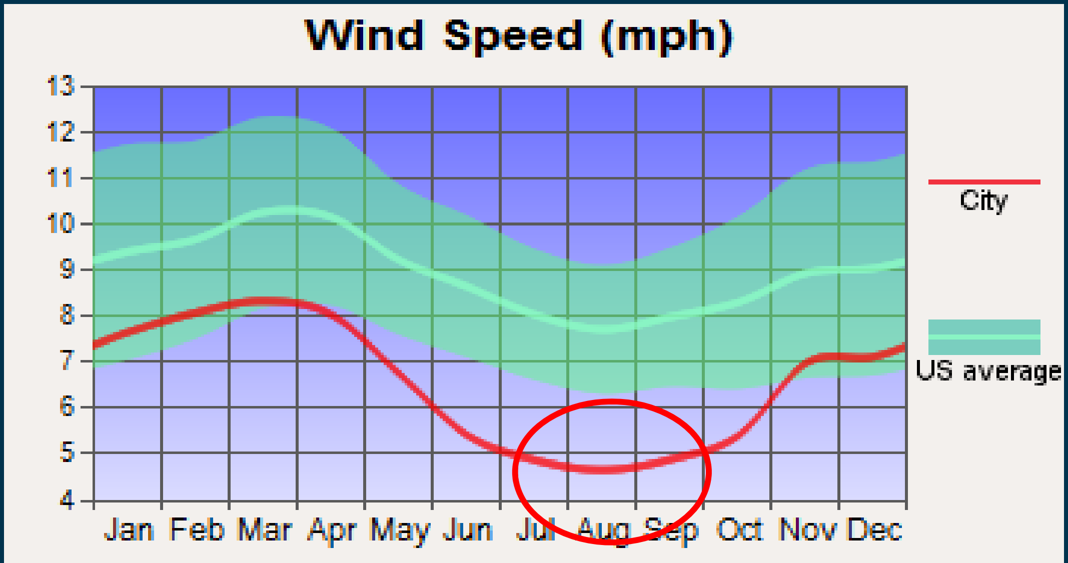

Modified from Fowler Ridge HCP by West, Inc.

# Results: WV 2012 and 2013

| Year | Treatment | Estimated bat fatalities/turbine/study period (95% CI) | Treatment decision framework |
|---|---|---|---|
| 2012 | 3.0 m/s (Control) | 74.5 (50.8–105.3) | 3-minute average from turbine |
| | 5.0 m/s (first 4 hours) | 72.7 (49.6–104.4) | 3-minute average from met tower[1] |
| | 5.0 m/s (all night) | 39.8 (25.9–59.7) | 3-minute average from met tower |
| | | | |
| 2013 | 3.0 m/s (Control) | 90.9 (57.2–153.5) | 10-minute average from turbine |
| | 5.0 m/s (all night) | 38.4 (18.4–68.9) | 10-minute average from met tower |
| | 6.5 m/s (all night) | 23.0 (11.3–45.9) | 10-minute average from met tower |

# Example of Cost-effectiveness

- Normal operation
  - ~ 91 (57.2–153.5) bats/turbine
- Turbine operation at winds speed >5 m/s
  - ~38 (18.6–68.9) bats/turbine
- Turbine operation at wind speeds >6.5 m/s
  - 23 (11.3–45.9) bats/turbine
- Arnett et al. 2011 showed similar fatality reduction
  - Loss of annual power at 5 m/s was 0.3%*
  - Loss of annual power at 6.5 m/s was 1%*

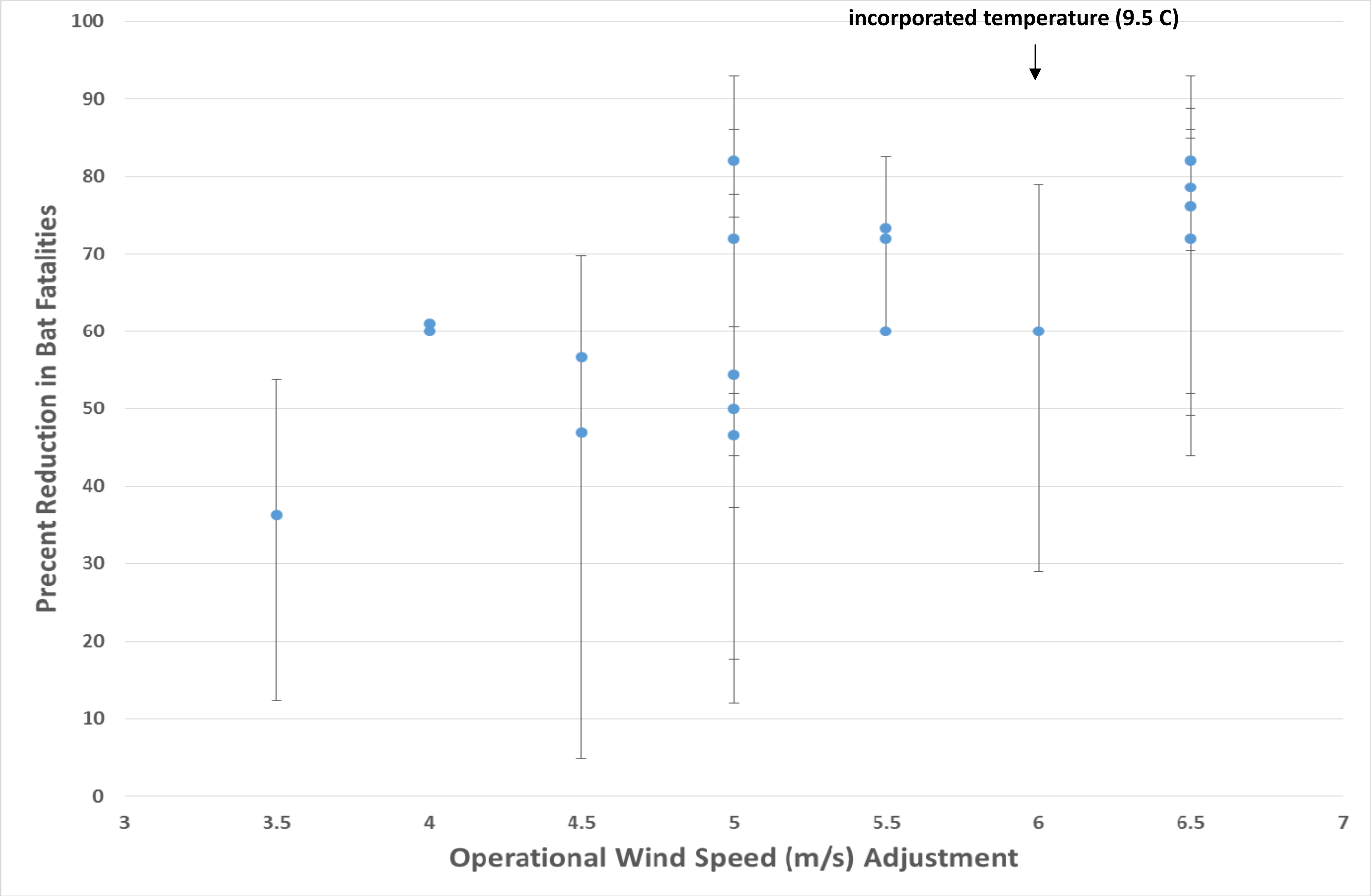




http://www.eia.gov/totalenergy/data/monthly/#appendices

* Influenced by many factors

# Synthesis of Operational Minimization



# Research Objectives WV 2015

- Improve the cost-effectiveness of "traditional" operational minimization strategies
- Treatments tested
  - Met 10-min (Control; standard operation at Facility)
    - Feathered below 5 m/s until 10-min rolling average based on the Met tower
  - Met 20-min
    - Feathered below 5 m/s until 20-min rolling average based on the Met tower
  - Turbine 20-min
    - Feathered below 5 m/s until 20-min rolling average based on the Turbine
- In theory, using a longer time period to initiate turbine start-up would allow
  - Turbines to operate at higher sustained wind speeds
  - Reduce the number of start-ups

## Why is this important?

# Background of the Concept

- Many turbines use a rolling average of wind speed over a period of time (e.g. 10 minutes) to initiate turbine start-up
  - In theory, hysteresis type events (e.g. wind gust) could inflate the measurement of wind speed and initiate start-up even though wind is still relatively low
- Wind speeds recorded downwind of the blades on the turbine's nacelle could affect wind speed measurements and thereby the effectiveness of this strategy.
- Cryan et al. 2014
  - Video results suggested bats tended to closely investigate turbines (i.e. blades, nacelle, monopole)
    - when blades were stationary or slowly free-wheeling (<1 RPM)
  - Fatality risk might exist when turbines start-up

# Hypothesis

- Longer measurement of wind speed before initiating start-up (i.e. 20-min vs. 10-min average)
  - Would have less fatalities
    - Sustained 5 m/s wind speed
    - Less operational changes
- Measurement of "free-flowing" wind speed (i.e. Met tower vs. Turbine anemometer)
  - Would have less fatalities
    - Wind speed measurement more accurate when not influenced by blades

# Methods WV 2015

- Daily searches at 15 of 23 turbines
- Randomized Block Design
  - Treatments changed nightly
- Fatality by treatment
  - Estimated fatality using Huso (2012)
  - Bayesian Poisson Regression
    - Modeled observed fatality by treatment
- Secondary analysis
  - Factors influenced bat fatality when turbines spinning
    - Logistic Regression Mixed Model

# Results WV 2015

- Comparison of turbine operations under treatments
  - Turbine (80 m) to Met tower (76 m) anemometer
    - 97% of time turbine anemometer measured a higher wind speed than Met tower
    - On average, turbine anemometer wind speed was 1.03 m/s higher than Met tower

# Results WV 2015: Comparison of Turbine Operations

| Metric | Met 10-min | Met 20-min | Turbine 20-min |
|---|---|---|---|
| Hours On | 5.77[a] | 5.88[a] | 7.05[b] |
| Hours Off (below 3 m/s) | 0.12[a] | 0.28[b] | 0.27[b] |
| Hours Curtailed | 4.71[a] | 4.43[a] | 3.27[b] |
| Curtailment Power Loss (MWh) | 0.63[a] | 0.60[a] | 0.21[b] |
| Number of Starts | 1.75[a] | 1.25[b] | 0.88[c] |
| Number of Stops | 2.08[a] | 1.60[b] | 1.03[c] |
| Number of Starts and Stops | 3.83[a] | 2.85[b] | 1.90[c] |

# Fatality by Treatment

- Huso (2012) estimated fatality
  - Significant difference between met 20-min and turbine 20-min

| | Bats/Turbine/Study Period |
|---|---|
| **Treatment** | Estimate |
| **Met 10-min** | 17.18 (8.10–29.63) |
| **Met 20-min** | 13.05 (6.08–24.00) |
| **Turbine 20-min** | 30.75 (15.38–70.95) |

# Poisson Regression

| | Treatment | Mean |
|---|---|---|
| **Expected Fatalities** | Met 10-min | 1.151 (0.572–1.920) |
| | Met 20-min | 0.808 (0.368–1.429) |
| | Turbine 20-min | 1.466 (0.783–2.336) |
| | | |
| **Percent Change** | Met 10-min to Met 20-min | -29.8 (-68.0–24.2) |
| | Met 10-min to Turbine 20-min | 27.4 (-32.0–103.0) |
| | Met 20-min to Turbine 20-min | 81.4 (-3.1–189.1) |

Not significantly different but trended similar to Estimated fatality results

# Poisson Regression

| Model | DIC[a] | ΔDIC[b] | $\omega_i^c$ |
|---|---|---|---|
| | | | |
| Null Model | 137.7 | 0 | 0.16 |
| Hours On | 138.0 | 0.3 | 0.13 |
| Treatments | 138.7 | 1.0 | 0.10 |
| Number Starts/Stops | 139 | 1.3 | 0.08 |
| Number Stops | 139.1 | 1.4 | 0.08 |
| Number Starts | 139.1 | 1.4 | 0.08 |
| Hours On, Number Stops | 139.9 | 2.2 | 0.05 |
| Hours On, Number Starts | 140.0 | 2.3 | 0.05 |
| Hours On, Number Starts/Stops | 140.1 | 2.4 | 0.05 |
| Treatment, Hours On | 140.3 | 2.6 | 0.04 |
| Treatment, Number Starts/Stops | 140.5 | 2.8 | 0.04 |
| Treatment, Number Starts | 140.5 | 2.8 | 0.04 |
| Treatment, Number Stops | 140.6 | 2.9 | 0.04 |
| Treatment, Hours On, Number Stops | 142.1 | 2.9 | 0.04 |
| Treatment, Hours On, Number Starts/Stops | 142.1 | 4.4 | 0.02 |
| Treatment, Hours On, Number Starts | 142.2 | 4.5 | 0.02 |

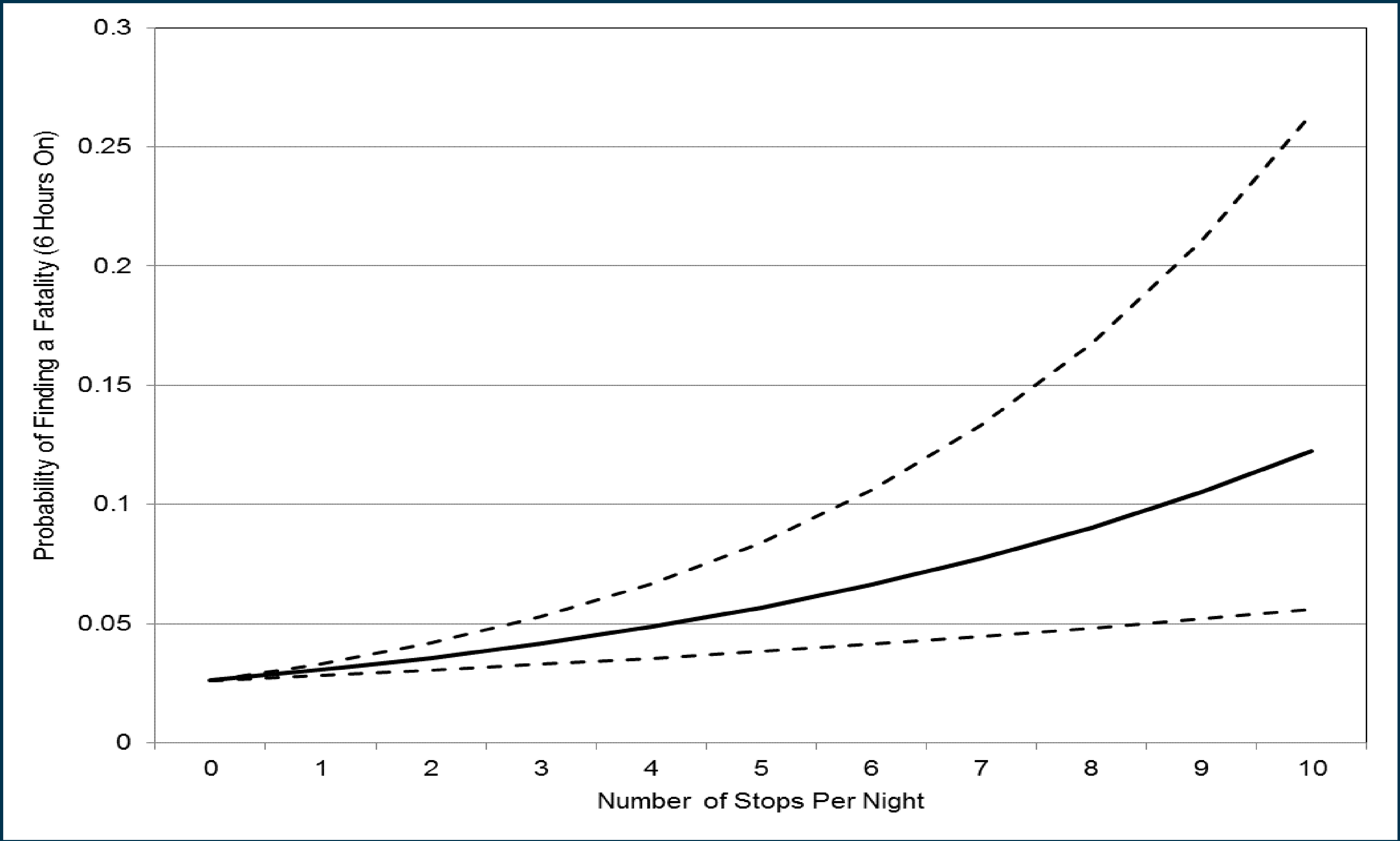
# Logistic Regression Mixed Models

- Best logistic regression mixed model of bat fatalities found per hour the turbine was spinning
  - Number of stops ($\beta$ =0.156, 95% CI: 0.001–0.311)
    - Stops/starts and starts were within one AIC unit

| Model | AIC[a] | ΔAIC[b] | $\omega_i$[c] |
|---|---|---|---|
| **Number of Stops** | 392.2 | 0 | 0.23 |
| **Number of Starts/Stops** | 392.5 | 0.3 | 0.19 |
| **Number of Starts** | 393.0 | 0.8 | 0.15 |
| **Null Model** | 393.7 | 1.5 | 0.11 |
| **Number of Stops, Temperature Change*** | 393.7 | 1.5 | 0.11 |
| **Number of Starts/Stops, Temperature Change*** | 394.0 | 1.8 | 0.09 |
| **Number of Starts, Temperature Change*** | 394.7 | 2.5 | 0.06 |
| **Temperature Change*** | 394.8 | 2.6 | 0.06 |

*Temperature change was determined to be an uninformative parameter (Arnold 2010)

# Fatality Probability to Turbine Stops




Number of starts and stops highly correlated, Pearson Correlation 0.946

# Summary WV 2015

- For this study
  - Treatment Met 20-min was the most cost-effective
    - Significantly less fatalities than Turbine 20-min
    - Less fatalities than Met 10-min
      - Not significant, likely related to small difference between treatments (i.e. difference of 10 minutes)
    - Less power loss and turbine on/off than Met 10-min
      - More energy production even though operated less
        - » Because of significantly more turbine on/off?
      - Less turbine "wear and tear"
  - Top model with turbine stops
    - Starts and stops highly correlated
    - Increase stops = wind speeds around the 5 m/s threshold

# Limitations

- We cannot separate bat fatality risk at
  - Low wind speeds (i.e. 5 m/s)
  - Risk when turbines start-ups,
    - Thermal videography might be a better tool to address the potential risk to bats during start-up
- All turbines were feathered to 5 m/s as the standard turbine operations for this facility
  - We could not compare results to normally operating turbines (i.e. cut-in speed at 3 m/s)

# Three-year Comparison

| Year | Treatment | Estimated bat fatalities/turbine/study period (95% CI) | Treatment decision framework |
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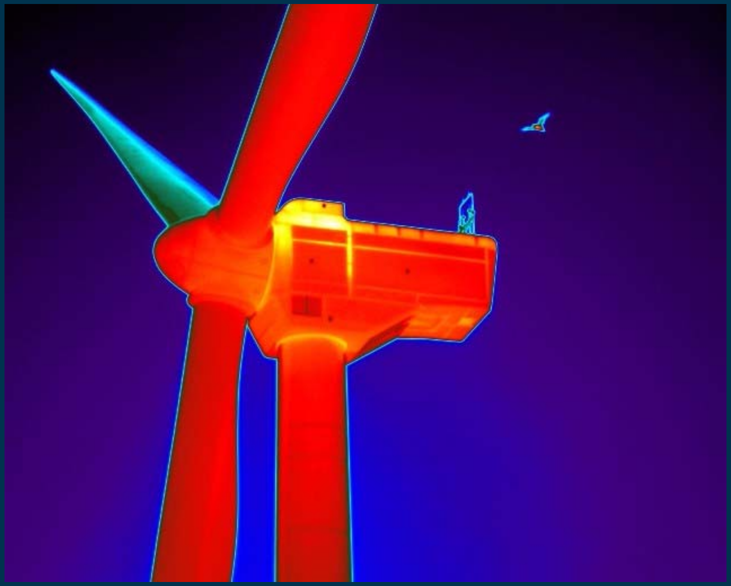
# Next Steps

- Replicate these results at other wind energy facility
  - Maybe increase time difference between treatments
- Test longer decision framework vs. higher cut-in speed
- Use thermal videography to
  - Determine risk during start-up
  - Determine lethal tip-speed



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