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DAIRY CATTLE DRINKING BEHAVIOR AND STRAY VOLTAGE EXPOSURE

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Summary:
Eight stanchioned lactating Holstein cows (with individual water bowls) were used to determine the water bowl contact time over a 1 day period. This work represents an ancillary question from an experiment that was designed to study aversion to transient and steady state stray voltage applied to the water bowls. Data was collected for the number of contacts and length of a water bowl contact for each cow. The average rate of arrival and average length of contact was calculated. A Poisson process for arrival was then assumed and Monte Carlo simulations used to estimate the number of cows that would be exposed to a transient voltage for herd sizes of 50, 100, and 200 cows.

Keywords:
Stray Voltage, Stanchioned Dairy Cows, Drinking Behavior, Transients

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INTRODUCTION

Stray voltage exposure occurs when an animal touches surfaces with unequal voltage potential and current flows through the animal. There are many possible sources of stray voltage [1]. In order for the exposure to occur, the voltage must be present when the animal is touching the contact points. Stray voltage can be categorized as either steady or transient. Steady voltages are normally caused by current being used to operate some electrical device and are generally considered to be present at the same or similar level for several minutes to several hours. Transient voltages are generally caused when an electrical device is started or stopped or by devices which operate intermittently such as an improperly grounded fencer. Transient voltages may occur as infrequently as once per day or as frequently as once per second (in the case of a faulty fencer).

Animals have a high probability of exposure when voltage potentials are always present or present very frequently (once per second) on devices which supply their only direct source of water. However, if voltage potentials are not present at all watering locations or not continuously present, the probability of exposure is reduced. Among the most common exposure locations are between the water bowls and the concrete floor of a barn. The purpose of this study was to assess exposure risks for stanchioned dairy cattle to intermittent voltage applied to the water line (water bowls).

MATERIALS AND METHODS

This study was motivated by an ancillary question from an experiment that studied drinking behavior of dairy cattle for steady state and transient exposures [2]. This paper uses data from eight cows for two days of background data collection. The cows selected for this study came from the UW-Madison herd. These cows had an average days-in-milk of 46 with a range from 10 to 67. The average lactation number was 3.3 with a range of 2 to 5. The diet consisted of 53 percent forage and 47 percent grain (dry matter basis). The forage was 45 to 48 percent dry matter. The grain was 90 percent dry matter. Each stall had its own water bowl. The total water requirements for dairy cows depend on a number of factors [3]. Estimates of total water requirements can be made [4]. The water values recorded for this work were from the individual water bowls--the water content of the feed was not used in these calculations.

On the first day of testing, there was no voltage placed on the water bowl. On the second day a 60 Hz steady voltage was placed on each water bowl that produced 1 mA of current through a 500 Ohm resistor using a standard stray voltage measurement contact (4@ x 4@ copper plate with 250 lbs. pressure placed on a towel wetted with salt solution). The current pathway for the cows was from muzzle to all four hooves. Two data acquisition units (Wave Riders) were used to record when each cow made contact with the water bowl. As an artifact from the main experiment, the water was off from five a.m. to eight a.m. (three hours) on both days. The total water volume consumed is for a 24-hour period. This was from eight a.m. one day to eight a.m. on the next. The cows were released from their stalls for milking at approximately seven a.m.. As the cows finished milking, they were sent out into an outside yard. Just prior to eight a.m. the cows were returned to the test stalls and manual water data collection began. On the second day of testing, the data acquisition units were turned on at fifteen minutes after eight a.m..

A steady source voltage of about 20 VAC (RMS average) was placed in series with 19k-Ohm resistor, a 330-Ohm resistor, and the water bowl. A 100k-Ohm resister was placed between the water bowl and stall base (in parallel with the cow). A 500-Ohm shunt resistor was connected between the water bowl and a copper contact on the floor. The source voltage was then adjusted so that 1 mA (RMS average) of current (+/- 10%) flowed through the 500-Ohm shunt resistors in all stalls. The shunt resistors and floor contacts were then removed and cows placed in the stalls. The data acquisition unit was connected across the 330 Ohm Resistor and measured an elevated voltage signal when the cow made contact with the water bowl.

Two filtering criteria were used on the raw data. One of these was magnitude of current flow. The 100k Ohm resistor was placed in parallel with the cow to eliminate noise produced by open circuit measurements. This resulted in a continuous small current flow through the circuit (but not the cow). The current flow through the circuit and voltage measured across the 330-Ohm resistor increased when a cow contacted the water bowl and reduced the total circuit resistance. A threshold of 0.18 mA through the circuit (0.06V across the 330-Ohm resistor) was used to indicate cow contact. This threshold level was confirmed with both the 500-ohm shunt resistor and by observation of cows drinking.

A second filtering criteria was used to establish the definition of an event. An event was defined to be any recorded contact that was 1 second or more apart from any other contact. For example, if a cow contacted the water bowl continuously for 1.4 seconds, 100 contact points would be recorded. This was considered a single event of 1.4 seconds duration. If the cow stopped drinking for 1.5 seconds and then touched the water bowl again for 0.5 seconds, a second event would have been recorded. The duration between events would have been 1.5 seconds and the duration of the second event would be 0.5 seconds.

The drinking behavior of cows was assumed to be the same over a prolonged period. The best estimate for mean contact time is then the total contact time for all cows divided by the total number of contacts. This is termed a weighted mean. The weighted mean was used for the average contact time and average time between contacts. These values were used in a stochastic process to estimate the number of cows drinking at any given time, and later in the generation of cow histories for the Monte Carlo simulations. Each Monte Carlo simulation was run for two thousand iterations on a Sun SPARCstation 10 (taking up to 18 hours of computer time each).

In this work, the time between contacts and the time spent in contact with the water bowl were both assumed to be exponentially distributed. This is a commonly used distribution for time between events in many disciplines. A perfect exponential would have approximately 63 percent of the observation below the mean. Our distributions had almost 75 percent of the observations below the mean for the drinking time and approximately 85 percent of the observations below the mean for time between drinks. This departure from the ideal could be caused by many possible factors. These include variation between cows and change in the contact rates with time of day. It is difficult to determine the true cause of the difference given that only eight cows were monitored with the data acquisition unit for one day in this study. When improved models for drinking behavior-- under varying environmental and housing conditions--become available, they can readily be incorporated into the methodology presented here.

RESULTS AND DISCUSSION

The mean water consumption increased 0.7 gallons on the second day of trial--this difference was not statistically significant. Four cows consumed less water on the second day and four cows consumed more water. The p-value for the difference between these days was 0.443 for a two-tailed paired t-test. There was 80 percent power to find a 2.6 gallon (or about 10%) difference between the two test days. The data for total water consumed is shown in Table 1. All the cows drank within 15 minutes of the start of the trial on both days.

Table 1. Water consumption for 24 hours for the no current day and the 1 milliamp day (Gallons).

	No Current Day	1 Milliamp Day	Difference
Stall 1	32.5	32.1	-0.4
Stall 2	26.7	29.3	2.6
Stall 3	29.6	27.4	-2.2
Stall 4	28.9	29.6	0.7
Stall 5	27.7	26	-1.7
Stall 6	22.1	26.4	4.3
Stall 7	32.1	31	-1.1
Stall 8	22.6	26.1	3.5
mean	27.8	28.5	0.7
Standard Deviation	3.9	2.4	2.5

Since there was no significant change in total water volume and no indication from visual observation that cows were affected, it is assumed that the cows were not affected by the presence of the voltage on the water bowl used to automatically record drinking behavior. This result was expected as the reaction level for these cows was well above 1 mA. The mean reaction level was 8.2 milliamps when 10 cycles of a 60 Hz signal was applied every 2 seconds [5].

The number of times a cow touched the water bowl and the average contact time recorded electronically are shown in Table 2. The non-weighted mean contact time was 9.2 seconds with a non-weighted mean time between contacts of 584.9 seconds. The weighted average mean contact time was 7.8 seconds and the weighted mean time between contacts was 497.6 seconds. The weighted (overall means) were used for the distributions in the exposure estimates in tables 4, 5 and 6.

Table 2. Cow water bowl contact time Summary Results.

Stall Number

	1	2	3	4	5	6	7	8
Cow Number	3964	3965	3894	936	3985	4061	3732	3967
Total Contact Time (Seconds)	2157.9	1299.2	1144.7	1492.4	715.3	1031.7	1240.1	1231.4
Mean Contact Time (Seconds)	11.0	12.6	16.1	11.7	2.7	6.1	7.4	5.7
Mean Time Between Contacts (Seconds)	410.7	804.4	1158.6	638.2	301.3	487.7	495.5	383.1
Percent Contact time	2.5	1.5	1.3	1.8	0.8	1.2	1.4	1.4
Number of Contacts	197	103	71	128	268	169	167	216
Days in Milk	55	57	51	62	10	16	67	48
Lactation	2	3	3	4	4	2	5	3

Risk of Exposure Modeling

The generation of summary statistics, as in Table 2, aids in the understanding of typical (or average) cow behavior. That data can be used to determine the percentage of time that a individual cow is in contact with the water bowl, and thus potentially exposed to transient voltages on the water bowl. A simple, stochastic, drinking-state model was used to estimate the number of cows that could be in contact with the water bowl at any given time, and hence the risk of exposure to a transient voltage on the water bowls [6]. Monte Carlo simulations were then used to estimate the number of exposures that a cow could receive over periods of 1 and 30 days. The Monte Carlo simulations take into account the back-off time, which is a measure of the reluctance of a cow to return to the bowl after a shock.

Stochastic Processes

Stochastic processes can be used to model the exposure risks for stanchioned dairy cows where each cow has its own water bowl. For example, if there were 100 cows in a barn, the number of cows drinking at any given time can range between 0 and 100. Therefore, there are 101 drinking states in the model (Figure 1). Suppose we are in state 2 (2 cows drinking), we can move only to state 1 (when one cow stops drinking) or to state 3 (if another cow starts drinking before any of the two stop). The directed lines (arcs) between states denote the possible changes (transitions) that can occur. The number on each arc specifies how fast we move from one state to the next.

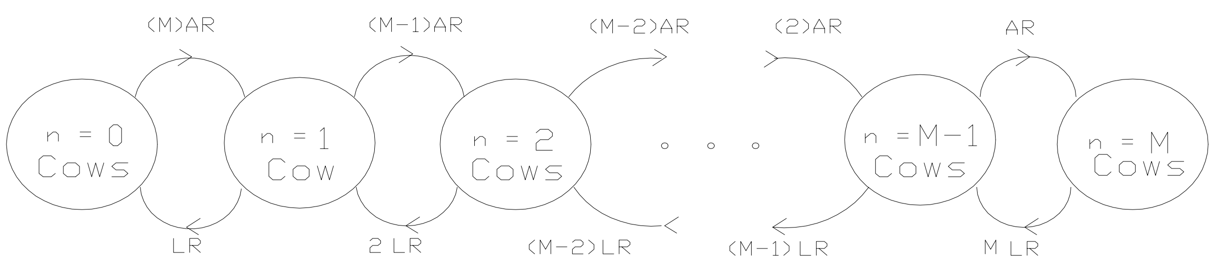

Figure 1. Drinking (contact) state model diagram for stanchioned dairy cows with individual water bowls that are connected by one water line.

A cow comes to the bowl at the Arrival Rate (AR), or every 1/AR seconds on average. This cow drinks for a period of time and then leaves its bowl at the Leaving Rate (LR), or spends 1/LR seconds drinking (in contact with the water bowl) on average. Note that when two cows are drinking, the rate of moving to the 1-cow-drinking state is 2LR because either of the two cows could be the next to finish. Similarly, the rate of moving to three cows drinking is 98AR because any of the 98 non-drinking cows could be the next to come to the bowl.

The odds, for example, that less than three cows are drinking at a given time (in particular, at the time of a randomly occurring transient), can be calculated using this modeling approach. Assuming that both the time between drinks and the time spent drinking are exponentially distributed, the probability that n cows are drinking (P_n) at any time is given by the following

$$P_n = P_o\left(\frac{M!}{(M-n)!n!}\right)\left(\frac{AR}{LR}\right)^{\wedge} n$$

formula. [7]

where

P_n: Probability of n cows drinking at a given time.
Po: Probability of no cows drinking at a given time.

$$P_o = \left(1+\frac{AR}{LR}\right)^{\wedge} -n$$

AR: Arrival rate to the water bowl (1/ average time between drinks).
LR: Leaving rate or average time to drink (1/average length of drinks).
M: Number of cows in the barn.
n: Number of cows drinking at any given time.

Clearly this depends on the number of cows in the barn M and the ratio of arrival rate divided by leaving rate. If this ratio gets bigger (either cows arrive faster or leave slower), then the cows are spending a larger percentage of their day at the bowl. Hence their risk of exposure to a transient voltage increases, and the odds are that more cows will be shocked by a transient. Similarly if the number of cows increase, we are also likely to see more cows exposed. For example, with an average drinking time of 7.8 seconds and an average time between drinks of 497.6 seconds, the probability of 3 cows being exposed at any instant to one transient in a herd of 50 is 3.5 percent whereas in a herd of 200 it is 22.5 percent.

Figure 2 shows the probability of n cows drinking at any given time for barns with 50, 100,and 200 cows with a average contact time of 7.8 seconds and an average time between contact of 497.6 seconds. As we can see from Figure 2, the more cows we have in the barn, the higher the probability that more cows are drinking at any given time.

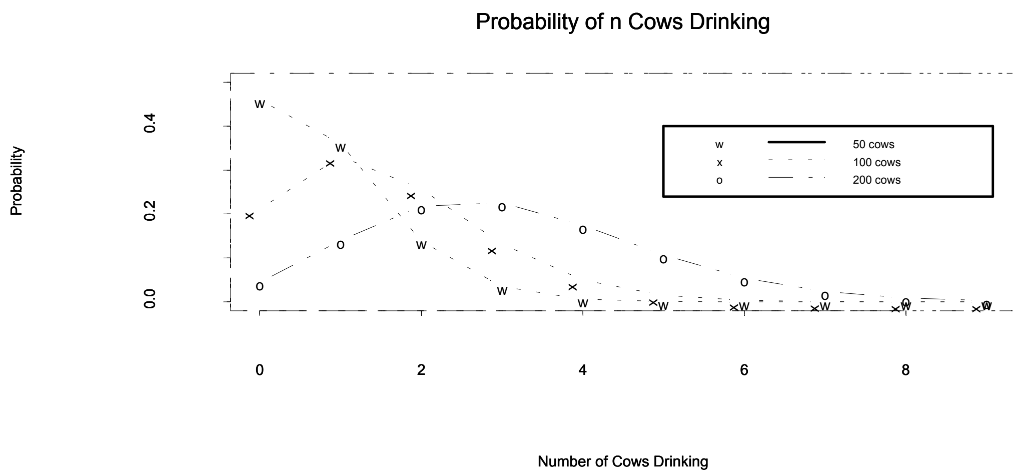

Figure 2. Plot of the probability that n number of cows are drinking at any time for 50, 100, and 200 cow barns where cows are stanchioned with individual water bowls.

Monte Carlo Simulations

The stochastic model developed in the previous section estimates the number of cows drinking at any point in time. However, it cannot be easily extended to take into account the behavior over a fixed period of time. Monte Carlo simulation can provide an estimate for the number of cows exposed for a given rate of transients. In addition, it can provide solutions for a wider range of models.

The model assumes that cows will drink at least once a day, and further, that cows back off from the bowl after a shock and take longer to return. Transients were randomly generated at a specified rate and assumed to be instantaneous. Cow drinking histories were generated for each individual cow in the herd, based on the weighted average arrival rates and contact times.

If a transient exposure occurs during a cow's drinking period, the cow backs off and will return later to the bowl. The average time to return to the water bowl was assumed to be ten times longer when exposure occurred than when it did not. The time to return to drinking after a shock was constrained to not exceed 24 hours.

One-day and 30-day periods with herd sizes of 50, 100 and 200 cows and occurrence of transients of 1, 10 and 100 per day were simulated. The parameters used in the simulation work are shown in Table 3. A value of 4976 seconds was chosen (or ten times the average time between drinks) for the average cow back-off time. This reflects an assumption that a cow would be more reticent to return to the bowl after a shock. The results are not sensitive to our choice for this parameter value, at a moderate rate for transient occurrence, since the number of shocks a cow receives is small relative to the number of times at the bowl. For example, the most shocked cow receives an average of 1.607 shocks during one day, in a herd of 100 cows, with transients occurring at a rate of 10 per day. We verified the afore-mentioned by running simulations for moderate transient rates, with an average back-off time equal to the mean time between drinks, and found negligible difference in the results.

Table 3. Parameters used in the Monte Carlo Simulations to generate Tables 4, 5, and 6.

Average time spent drinking (1/DR)	7.8 seconds
Average time between drinks (1/AR)	497.6 seconds
Average cow back off time after receiving a shock	4976 seconds
Maximum time without drinking	1 day

Table 4 shows the expected number of exposures for a 30-day period. For example, it would be expected that about 37 percent of the herd would receive between 1 and 5 shocks if on average one transient was occurring each day for 30 days. So if there were 100 cows, it would be expected that 37 of them would receive between 1 and 5 shocks. If there were 120 cows, it is expected that approximately 45 of the cows would receive 1 to 5 shocks.

Table 4. Expected percent of the herd that is exposed to 0, 1 to 5, or greater than 5 shocks over a 30 day period.

	Number of Exposures		
	0	1-5	>5
1 Transient per day	62.8 %	37.2 %	0.0
10 Transients per day	1.0 %	67.9 %	31.1 %
100 Transients per day	0.0	0.0	100.0 %

Table 5 shows the average number of exposures that a cow would receive over 1 and 30 days. For example, a given cow would be exposed on average 4.6 times if there were 10 transients per day for 30 days. Alternatively, in a herd of 100 cows, the expected total number of shocks would be 460 in the same time period.

Table 5. Expected number of exposures for a given cow and the standard error of the estimate.

	1 Day	30 Days
1 Transient per day	0.016 (0.000)	0.465 (0.002)
10 Transients per day	0.155 (0.001)	4.588 (0.008)
100 Transients per day	1.416 (0.004)	42.52 (0.021)

The expected number of exposures for the cow receiving the greatest number of exposures is shown in Table 6. For example, if there were 100 randomly occurring transients in one day, it would be expected that at least one cow would receive about 5 shocks.

Table 6. Expected number of exposures for the most exposed cow and the standard error of the estimate.

	1 Day			30 Days		
	50 Cows	100 Cows	200 Cows	50 Cows	100 Cows	200 Cows
1 Transient per day	0.410 (0.011)	0.576 (0.012)	0.634 (0.012)	2.452 (0.015)	2.765 (0.015)	3.079 (0.015)
10 Transients per day	1.386 (0.012)	1.607 (0.013)	1.860 (0.012)	9.936 (0.031)	10.611 (0.030)	11.266 (0.028)
100 Transients per day	4.285 (0.017)	4.683 (0.018)	5.041 (0.017)	56.58 (0.071)	58.221 (0.067)	59.86 (0.064)

SUMMARY AND CONCLUSIONS

This study demonstrates a method for estimating the probability of dairy cow exposure to transient voltages. Estimates of the exposure risks and the factors affecting these probabilities have been presented. The drinking behavior data used to estimate the probability of exposure were from stanchioned dairy cattle with individual water bowls in each stall as the only direct source of water for each cow. The applicability of these results depends on similarity of drinking behavior and validity of the underlying distributional assumptions.

On average, the eight Holstein cows used in this study drank about 29 gallons of water in 24 hours. Different amounts of water consumption would presumably result in different contact times and exposure risk. The exposure estimates in Table 4,5, and 6 are based on a back off time that is ten times greater than the mean arrival time. If a cow was not shocked on the next drink, it then went back to its normal drinking behavior. The severity of the exposure and individual sensitivity of the cow exposed would influence these behaviors. The behavior of cows that share waterers or are housed in free-stall barns will be different. The occurrence of transients were assumed to be randomly distributed over the day. Depending on the source of transient voltages, this may not be the case.

The method presented could be used to adjust exposure estimates for drinking behavior of cows under varying environmental and housing conditions. Further work needs to be done to better understand the nature of the distributions of cow contact times for various environmental conditions.

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