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J. Clausen

A. M. Parkhurst

T. L. Mader

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LOGISTIC REGRESSION ANALYSIS TO DETERMINE FACTORS CONTRIBUTING TO SUMMER FEEDLOT DEATHS

J. Clausen[1], A. M. Parkhurst[1], and T. L. Mader[2]

[1]Department of Statistics, University of Nebraska-Lincoln

[2]Department of Animal Science, University of Nebraska-Lincoln

Abstract
Summer heat has already been identified as a major factor for cattle deaths in the feedlot. This study attempts to assess what other factors contribute to and/or influence cattle deaths. Identifying multiple factors that contribute to summer feedlot deaths could aid feedlot managers in implementation of mitigation strategies and minimize the loss of nearly finished cattle. Daily pen, cattle, and nutritional characteristics were recorded and included in this generalized linear mixed model analysis. Cattle data were obtained from cattle pens at a single location from July 1, 2010 to July 31, 2010. Hourly weather data were acquired from this feed yard while solar radiation was received from a neighboring town. Rather than using multiple weather variables, a single comprehensive climate index that summarizes several weather variables is used to capture the apparent feel of the weather. After reviewing the data, a statistical model is developed and odds ratios are computed for statistical inference. According to these odds ratios, cattle fed on severe west slopes had significantly higher odds of death than other types of slopes. Analysis of feed intake indicates pens consuming 16pounds of feed per head or less during July 16 – 18 have higher odds of death than other consumption levels.

1. Introduction
In the Midwest and Plain states, losses of confined cattle exceeded 2,000 head during each of seven separate heat waves, which occurred over the past 15 years. The heat waves of 1995, 1999, 2006, and 2009 were particularly severe with documented cattle losses in Midwestern states approaching 5,000 or more head each year (Mader, 2003; Mader et al. 2006; Mader and Gaughan, 2009). Economic losses from reduced cattle performance likely exceed those associated with cattle death losses (approximately $1,400 per head) by 5- to 10-fold. In July 2010 another Midwestern cattle feedlot experienced substantial deaths during an adverse heat episode. To investigate possible contributors to death loss associated with hot weather conditions, pen, cattle, and nutritional characteristics are analyzed at a single location. Furthermore, both quantity and associated changes of daily feed intake are examined to assess effects of metabolic heat flux. Major interest is on the type of ration and dietary feed additive consumed.

2. Materials and Methods
2.1 Data Set
Feedlot data were obtained from a Midwest cattle feedlot for the period from July 1, 2010 to July 31, 2010. Since the focus of this study was on the deadly heat wave that occurred between July 16 and July 20, the data set was reduced to the period July 9, 2010 to July 23, 2010. This feed yard contains a total of 188 pens of cattle, with 174 pens for the period of interest. Management at this feed yard maintained daily records for variables contained in their database.

Following are descriptions of variables, italicized, that appear in the feedlot data set. *PenDailyLotNumber* is a number used to keep track of groups of cattle owned by individuals. If

groups of cattle are large, multiple pens in the feedlot may have the same *PenDailyLotNumber*. *PenDailyPenNumber* is a number assigned to a pen of cattle to identify the location of the pen at the feed yard. These numbers are subjectively assigned. *PenDailyDate* is the day when values for each variable are recorded. Each line in the data set represents an observation recorded on a particular pen on a given day.

Several adjustments to the original data set were needed for this analysis. Because some rations are only given to a few pens on a particular day, days are grouped into three periods in an attempt to increase the number of pens receiving those rations for these periods. *Period* is a categorical variable that indicates the period when the observation occurred. Heat1 is July 9 – 15, Heat2 is July 16 – 18, and Heat3 is July 19 – 23. This division can be thought of as pre-heatwave, during heatwave, and post-heatwave periods.

Other adjustments required new variables to identify the number of cattle that died on a given day and cumulative deaths for each *PenDailyLotNumber*. Because feedlot personnel did not record most cattle deaths for July 16 – 17 until Sunday July 18, deaths recorded on July 18 were re-distributed to July 16, 17, and 18. According to managers, an estimated 25% of the deaths occurred on July 16, 50% on July 17, and 25% on July 18. Therefore, *PenDailyDeadsDistributed* is the number of cattle that died in a pen on a particular day after distributing July 18 deaths to July 16, 17, and 18. If July 16 or 17 had some deaths already recorded, the July 18 distributed deaths were added to these deaths. Then, *PenDailyHeadCountDistributed* is the number of live cattle in the pen for a given day, and *PenDailyPenTotal* is the total number of live and dead cattle in a pen for a particular day. Next, the proportion of dead cattle in a pen on a given day is *ProportionDead* which is *PenDailyDeadsDistributed* divided by *PenDailyPenTotal*. This is how the occurrences of deaths were identified.

Further variable definitions are as follows: *PenDailySex* is the gender of the animals in the pen with categories H (heifers), S (steers), and M (mixed – both heifers and steers). *PenDailyAvgWeight* is the estimated average weight of an animal in the pen computed by taking the total weight of all animals in the pen divided by the number of animals in the pen. Because the cattle are not weighed every day, these values are estimated, based on feed intake and historical feedlot performance records for the type of cattle being fed. *PenFeedIntake* records the total weight of feed given to cattle in a particular pen on a certain day. *DMIPerHead* is *PenFeedIntake* divided by *PenDailyPenTotal* to obtain an estimated amount of feed consumed by individual animals within a pen. *DMIDailyChange* is *DMIPerHead* today minus *DMIPerHead* received the previous day. Therefore, *DMIDailyChange* will be positive if cattle receive more feed today and negative if cattle receive less feed today in comparison to yesterday. If the amount of feed does not change, then *DMIDailyChange* will be zero. Because groups of cattle are occasionally moved from pen to pen or new groups enter the feed yard, *DMIDailyChange* will not be available until the second day for which cattle are in their new pen.

Since ration is the focus for this data analysis, the following variables are of interest. *BmRation* is the type of feed given to cattle in a pen. Nine different rations were distributed to pens throughout the middle of July. Rations 1, 2, and 3 are roughage-based feed consisting of approximately 60%, 75%, and 85% corn, respectively. Rations 4 and 14 are steer and heifer finishing rations, respectively. Ration 7 is a High-DGS (Distiller Grains) grower with energy

content similar to Ration 2. Rations 41 and 42 are steer and heifer rations containing Beta-agonists; while ration 47 is a steer ration containing other Beta-agonists. *RationGroup* is the grouping of certain rations. *PenDailyAvgDOF* is the number of days a group of cattle have been fed at the feed yard. The longer cattle are at the feed yard, the larger the *PenDailyAvgDOF*. *NumberDaysOnRation* and *DaysOnAOrBRation* record the number of days a pen receives a given ration or rations 41, 42, or 47, respectively. *NumberDaysOnRation* is a quantitative variable while *DaysOnAOrBRation* is a categorical variable.

More pen characteristics are provided by these next variables. *BunkLengthFt* determines the amount of space available for cattle to eat their feed from bunks. *PenDepthFt* is the length of the pen from front to back. *PenSqFt* is the amount of area in the pen, recorded in squared feet. *SqFtPerHead* which gives the amount of area for each animal is defined as *PenSqFt* divided by *PenDailyPenTotal*. *Slope* indicates the direction the pen is sloping. Flat, moderate east (ME), moderate northeast (MNE), moderate northwest (MNW), moderate west (MW), north (Nor), severe west (SevW), and south (Sou) are the possible slope directions at this feed yard. *WaterTanks* is the number of both fixed water tanks in the pen and galvanized water tanks added to the pen during the heat period. There are water tank combinations appearing in this data set: One shared and zero galvanized (1S0G), one not shared and zero galvanized (1NS0G), one shared and one galvanized (1S1G), and one not shared and one galvanized (1NS1G).

Lastly, since many of the quantitative variables reflect transitions of cattle among pens, nearly all quantitative variables are converted into new categorical variables for ease of interpretation. *PenDailyAvgWeightCateg*, *DMIPerHeadCateg*, *DMIDailyChangeCateg*, *PenDailyAvgDOFCateg*, *BunkLengthFtCateg*, *PenDepthFtCateg*, and *SqFtPerHeadCateg* are all four level category variables formed from quartiles. For simplicity, midpoints of quartiles will be used when referring to quartiles.

Hourly weather data were available at this Midwest cattle feedlot from July 9 – July 23 due to availability of equipment used by other researchers. All weather variables except solar radiation were obtained at the feed yard. Solar radiation values were obtained from a neighboring town approximately 4 miles away. Since the feedlot data have only one entry for each day, the median of the 24 hourly values of a comprehensive climate index was used to create one daily value. The comprehensive climate index developed by Mader et al. (2010) uses ambient temperature, relative humidity, wind speed, and solar radiation to provide a measure to capture the conditions of the day. Since this index contains multiple weather measures, *Median CCIv3.2, (°F)* is the one weather variable that appears in this analysis and is always a quantitative variable. It provides a relative indicator of the environmental conditions surrounding an animal. It mathematically quantifies how RAD, WS, and RH interact with ambient temperature (Ta) to produce an apparent temperature. The CCI was developed under environmental conditions associated with Ta from approximately −30 to 45°C and provides an adjustment to Ta for relative humidity, wind speed, and radiation. (Mader, 2010) *Lagged Median CCI* is the previous day's Median CCIv3.2. Yesterday's Median CCI is considered because this value might be associated with the current values for many of the variables used to describe the data.

2.2 Statistical Methods
Data analysis is implemented using the Statistical Analysis System (SAS). Descriptive statistics are obtained using proc freq, proc means, and proc gplot SAS procedures to summarize and plot

collected feed yard data. Within SAS, the proc glimmix procedure is used to construct a statistical model for proportions data. The model has a Linear Predictor,

$$\eta_{ijklmnrst} = \eta + \alpha_i + \beta_j + \gamma_k + \delta_l + \rho_m + \tau_n + \phi_r + d_s + \theta X_{t(i)} + (\alpha\rho)_{im} + (\alpha\tau)_{in} + (\delta\phi)_{lr}$$

i = Heat1, Heat2, Heat3   (α =Period)
j = 4, 14, 12-37, 41, 42-47   (β=Ration Group)
k = Flat, ME, MNE, MNW, MW, Nor, SevW, Sou   (γ=Slope)
l = Q1, Q2, Q3, Q4   (δ=Average Weight)
m = Q1, Q2, Q3, Q4   (ρ=DMI)
n = Q1, Q2, Q3, Q4   (τ=DMI Change)
r = Q1, Q2, Q3, Q4   (ϕ=Square Feet)
s = 1, 2, 3, 4, . . . , p   where p is the number of pens at level i, j,   (d=Pen)
k, l, m, n, r
t = 83.81, 83.61, 88.62, 83.47, 87.92, 89.4, 86.19, 93.47, 92.2,   (X=Median CCI)
92.38, 86.14, 82.19, 85.02, 85.37,85.23

Response Variable: $y_{ijklmnrst} \mid d_s \sim \text{Binomial}(N_{ijklmnrst}, \pi_{ijklmnrst})$

Distributional Assumption: $d_s \sim \text{iid } N(0, \sigma_d^2)$

Link: $\eta_{ijklmnrst} = \log\left(\dfrac{\pi_{ijklmnrst}}{1 - \pi_{ijklmnrst}}\right) = \text{logit}(\pi_{ijklmnrst})$

$y_{ijklmnrst}$ is number of cattle deaths during i^{th} period, receiving j^{th} ration, on k^{th} slope, in l^{th} pen
average weight quartile, m^{th} dry matter intake quartile, n^{th} dry matter intake change quartile, r^{th} square feet per head quartile for s^{th} pen, and t^{th} median CCI.

$N_{ijklmnrst}$ is number of cattle during i^{th} period, receiving j^{th} ration, on k^{th} slope, in l^{th} pen
average weight quartile, m^{th} dry matter intake quartile, n^{th} dry matter intake change quartile, r^{th} square feet per head quartile for s^{th} pen, and t^{th} median CCI.

$\pi_{ijklmnrst}$ is population probability of death during i^{th} period, receiving j^{th} ration, on k^{th} slope, in l^{th}
pen average weight quartile, m^{th} dry matter intake quartile, n^{th} dry matter intake change quartile, r^{th} square feet per head quartile for s^{th} pen, and t^{th} median CCI.

σ_d^2 is the population variance for the sth pen

η is the overall mean

α_i is the fixed effect of the ith level of period

β_j is the fixed effect of the jth level of ration group

γ_k is the fixed effect of the kth level of slope

δ_l is the fixed effect of the lth pen average weight quartile

ρ_m is the fixed effect of the mth dry matter intake per head quartile

τ_n is the fixed effect of the nth dry matter intake change quartile

ϕ_r is the fixed effect of the rth square feet per head quartile

d_s is the random effect of the sth pen

θ is the slope coefficient for median CCI

$X_{t(i)}$ is the t-th level of median CCI within the ith period, a direct variable

$(\alpha\rho)_{im}$ is the fixed interaction effect of the ith level of period and mth dry matter intake per head quartile

$(\alpha\tau)_{in}$ is the fixed interaction effect of the ith level of period and nth dry matter intake change quartile

$(\delta\phi)_{lr}$ is the fixed interaction effect of the lth pen average weight quartile and the rth square feet per head quartile

Since the feedlot data do not have a repeated measure experimental design, proc glimmix was not executed in a fashion consistent with a repeated measures study. However, several proc glimmix options are added to assist in the analysis of the data. A Laplace integral approximation procedure is implemented in order for a real likelihood function to be available for likelihood ratio tests and information criteria. Another reason for the Laplace approximation procedure is proc glimmix has difficulty converging without this option. In addition, the Morel et al. (2003) bias correction to the classical sandwich estimator is used to help control the bias in standard errors. If standard errors are underestimated, then F-statistics are overestimated, and the Type I error rate increases.

The first step in the model building procedure was forward selection with significance level for a variable to enter (sle) the model ≤ 0.20. The higher significance level is used to control the Type II error because not including an important variable is much worse than including an unimportant variable. Then, backwards elimination was performed with the significance to stay set to ≤ 0.20. For the final model, interaction terms were with added with sle ≤ 0.20.

The fit statistics, -2 log likelihood and information criteria, provide other method ways to compare competing models. Since the Laplace integral approximation method results in using a real likelihood function, these information criteria can be used for model comparisons. A model with smaller information criteria is preferable. Furthermore, the Pearson Chi-Square/DF is a valid over-dispersion statistic for the conditional distribution of count data. If this value is near 1, then over-dispersion is not considered a problem for the model. Because the data are not being modeled as counts, but rather as proportions, the Pearson Chi-Square/DF does not offer formal insight into the appropriateness of the model.

3. Results and Discussion
3.1 Descriptive Statistics
In order to understand the structure of this survey data, descriptive statistics and frequency table with non-zero pen counts are analyzed to ensure that information is available for certain levels of variables. 174 pens from the feed yard are included in this analysis and counted each day from July 9 – July 23. However, data from some pens were not recorded on certain days; therefore, the total number of pens is 2475. Thus, total pen count may change due to missing data for various variables.

Since each day has at least 160 pens, sufficient information is available to observe the death counts on each day included in the analysis. Before the heat wave, few deaths occurred. Then, as

weather conditions became hotter, deaths rose dramatically. Finally, deaths began to decline. Thus, days are combined into three periods: Pre-wave Heat1 from July 9 – July 15 (9 deaths); Heat2 from July 16 – July 18 (639 deaths); and Post-waveHeat3 from July 19 – July 23 (40 deaths).

Each ration has at least 29 pens. Rations 1, 2, 3, 7, 41, 42, and 47 have 5 or less deaths. Because these death counts are extremely small, grouping rations is needed in order to improve the validity of inference. Rations 1, 2, 3, and 7 are grouped together because of similar roughed-based feed characteristics (8 deaths); rations 41, 42, and 47 form a Beta-agonist group with 12 deaths; and rations 4 and 14 remain in their own groups because of abundant death counts of 175 and 493, respectively.

Each slope has information since pen frequencies are greater than 100. Pens with flat slopes appear most frequently (n=826). Flat and moderate west have the largest number of deaths (over 100). Severe west and moderate east have near 100. Moderate northeast and south have number of death around 50, while north and moderate northwest have the smallest number of deaths ($\leq$ 20).

Most deaths occurred when *PenDailyAvgWeight* was in second and third quartiles. Lighter cattle with an average weight about 670 lbs had the least number of deaths, and heavier cattle with an average weight near 1240 lbs had the second smallest death count. This feed yard contained far more heifers than steers or pens with both heifers and steers. Consequently, heifers had the greatest number of deaths while steers and mixed pens had many fewer deaths. Accounting for *PenDailyAvgWeight*, heifers had large death counts in all weight quartiles while steers and mixed pens tend to have deaths in the upper weight quartiles. When analyzing deaths, gender is confounded with weight.

Since each day and ration combination contains at least one pen, we can summarize the daily deaths for each ration. Most days have no death or a small number of deaths (1~2 deaths), except days 07/16, 07/17, 07/18 (136 deaths, 370 deaths, 133 deaths, respectively). When constructing a statistical model for these data, days are grouped into periods in order to eliminate zero deaths. Even if rations 1, 2, 3, and 7 were already grouped together, their death count would still be zero for many days in July. Therefore, both rations and days must be grouped to eliminate small cell counts.

Ration and *PenDailyAvgWeight* combinations offer an example when the pen counts are occasionally zero, Table 1. The data set contains pens for those *Ration* and *PenDailyAvgWeight* combinations and the death counts that have statistical meaning. Consequently, non-highlighted entries indicate no pen data are present in the data set for the particular ration and pen average weight combination, and of course, no deaths occurred. Observing the highlighted cells, one should notice that rations 1, 2, and 7 are fed to lighter cattle while rations 41, 42, and 47 are fed to heavier cattle. Only rations 3, 4, and 14 are fed to cattle in all weight categories. Confounding such as this inhibits the ability to analyze interactions between certain variables because sufficient information is not available for all factor level combinations.

Table 1: Frequency of *Ration* by *PenDailyAvgWeightCateg* Death Counts

Ration	PenDailyAvgWeightCateg				Total
	Q1	Q2	Q3	Q4	
1	2	0	0	0	2
2	0	0	0	0	0
3	4	0	0	0	4
4	1	46	53	75	175
7	2	0	0	0	2
14	36	171	187	99	493
41	0	0	0	5	5
42	0	0	1	1	2
47	0	0	0	5	5
Total	45	217	241	185	688

After rations and days are combined into ration groups, the death counts are obtained. Rations 4 and 14 during Heat2 (heat) result in the greatest number of deaths. Small death counts continue to be a problem for certain combinations. Seven out of 12 ration and period interactions contain 4 deaths or less. Due to these sparse death counts, analyzing ration group and period interaction is not considered. Even though interaction counts are sparse, grouping rations and grouping days will allow ration group and period to have large enough death counts for inclusion in building a statistical model. Lastly, pen counts are non-zero for each ration group and period combination.

In addition to frequency table, graphs can provide insight for understanding conditions throughout the two-week period. As noted earlier, weather conditions became extremely hot during July 16 – July 18. A plot of the Median CCI of the 24 hourly CCI readings vs. Day shows spikes in Median CCI to about 88 F and 89 F on July 11, July 13, and July 14 with a weak cooling day on July 12, Figure 1. A mean daily CCI of 88 F or above is severe and could potentially lead to cattle deaths (Mader, 2011). From July 14, Median CCI declines slightly on July 15 and abruptly spikes on July 16 to approximately 93 F. At this point, cattle have already experienced high CCI values for several days. But now, cattle begin to encounter severe CCI values over a three-day period. Prolonged exposure to these CCI values helped contribute to many deaths at the feed yard, as shown in Table 2. After July 18, Median CCI values rapidly decline the next two days while returning to regular summer conditions within the next three days. Even though the Median CCI declined on July 19, 30 cattle died after surviving the worst weather conditions.

Figure 1: *Median CCIv3.2*, (F°), for Each Day
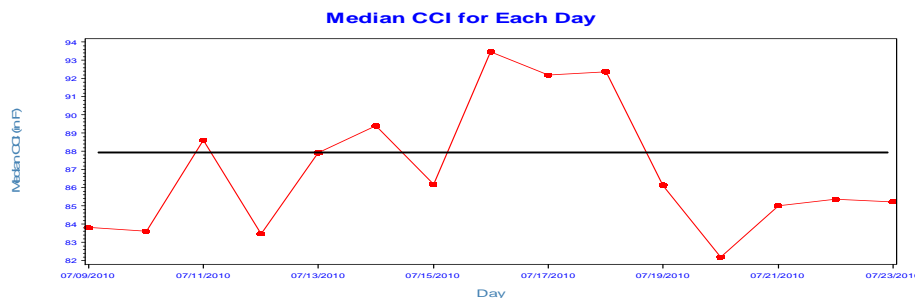
Change in the amount of feed consumed by cattle from one day to the next is a way to monitor the body energy level during intense summer weather conditions. According to feed yard protocol, operators do not purposely restrict the amount of feed consumed by cattle at the feed yard. If some feed remained in the bunks at feeding time, then the operators would reduce the amount of feed given to the pen. Figure 2 shows median change in dry matter intake for pens consuming a particular ration on a specific day. Median change in matter intake fluctuates around zero from July 9 – July 15. Then, July 16 shows slight declines in median dry matter intake for rations 3, 4, 14, 41, 42, and 47. After experiencing a median CCI around 93 F on July 16, July 17 indicates cattle are reaching their maximum energy consumption capacity, and the change in dry matter intake decreases dramatically for rations 4, 14, 41, 42, and 47. After July 17, these cattle regain their appetite and compensate in feed intake even though median CCI values are still high (Mader, 2011). Note that when median CCI troughed at 82 F on July 20, all rations had a positive change in median dry matter intake.

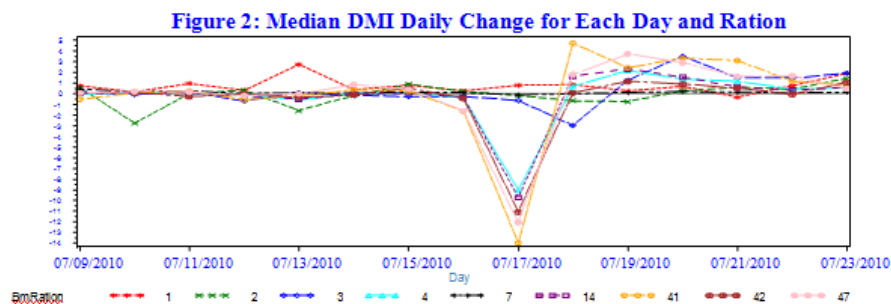Figure 2: Median DMI Daily Change for Each Day and Ration

Figure 3 summarizes daily activity at the feed yard. The average of proportions computed for each pen receiving a particular ration on a certain day is used to observe days when the proportion of deaths abruptly changes. For July 9 – July 15, average proportion dead remains near zero. Overall, as median CCI increases for July 16 – July 18, average proportion dead increases during July 16 – 17. Then, as median CCI tends to decrease for July 18 – 23, the average proportion dead declines as well. Hence, average proportion dead tends to oscillate in conjunction with median CCI. Of the rations, ration 41 has two large peaks on July 17 and 19. Some cattle on ration 41 died after the first day of median CCI values in the 90 F's while others died after the third day of high CCI values.

Figure 3: Average Proportion Dead for Each Day and Ration
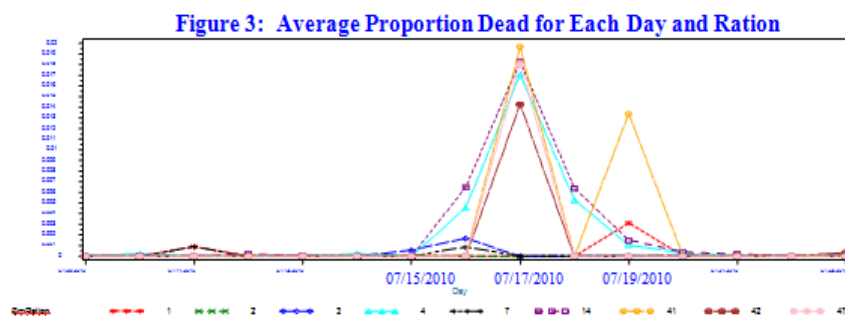
Finally, the average proportion dead for each gender and pen average weight quartile is summarized in Figure 4. As for the mixed pens containing both heifers and steers, the average proportion dead remains at zero until Q4 (1240 lbs) is reached which results in the highest

average proportion dead in the plot. Next, steers show a large spike in average proportion dead at Q2 (900 lbs) of pen average weight and then slightly declines for Q3 (1040 lbs) while increasing moderately at Q4 (1240 lbs). Lastly, heifers show a steady incline in the average proportion dead for the first three quartiles (670, 900, and 1040 lbs) and moderately declines for Q4 (1240 lbs). Overall, all three gender categories indicate an increase in the average proportion dead as pen average weight increases.

Figure 4: Average Proportion Dead for Each Gender and Weight Quartile
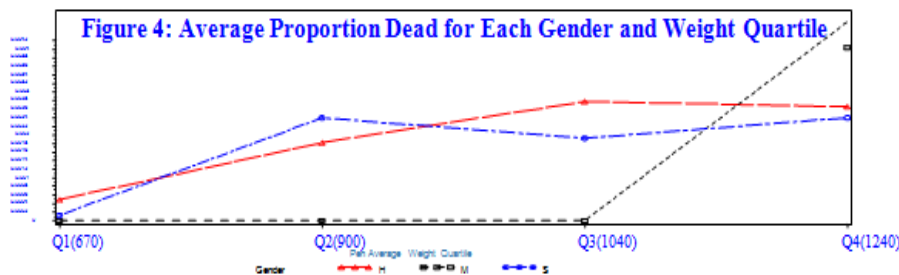
3.2 Statistical Model Results

Overall fit of the final model and a summary are provided in Table 2. The Type III Tests of Fixed Effects output displays the significance of each term in the final model. Even though DMI Daily Change Category has a p-value much greater than 0.20, this main effect remains in the model because this term is involved in a significant two-way interaction with Period. Because Ration Group and Slope are not involved in interactions, these terms will be analyzed as main effects. As for the other terms involved in interactions, only those interactions will be analyzed and not their main effects.

Table 2: Model Summary for the fixed effects from proc glimmix

Effects	P-value
Period	0.0009
Ration_Group	0.1741
Slope	0.0695
PenDailyAvgWeightCateg	<.0001
DMI_per_headCateg	<.0001
DMI_Daily_ChangeCateg	0.7767
sq_ft_per_headCateg	0.0297
Median_CCIv3_2_F	0.1468
*Period*DMI_per_headCateg*	0.0261
*Period*DMI_Daily_ChangeCateg*	0.0992
*PenDailyAvgWeightCateg*sq_ft_per_headCateg*	0.0480

Simple effects of one factor at specific levels of the other factor are shown in Table 3 A. Conditioning on level of *DMIPerHeadCateg* quartiles, the estimated odds of death for one period are compared with another period. Only four comparisons show significant differences in the odds of death. When cattle fall into Q2 (18 lbs) of *DMIPerHeadCateg*, the odds of death for Heat2 (heat) are significantly larger than Heat3 (post-heat) (Lower Odds Ratio = 1.256 > 1). When cattle are in Q3 (21 lbs) of *DMIPerHeadCateg*, Heat2 has a larger odds of death ratio than both Heat1 (pre-heat) (Heat1 vs. Heat2 Upper Odds Ratio = 0.219 <1) and Heat3 (Heat2 vs.

Heat3 Lower Odds Ratio = 1.058 >1). Lastly, Q4 (28 lbs) of *DMIPerHeadCateg* shows significantly lower odds of death for Heat1 than Heat2 (Upper Odds Ratio = 0.224 <1). For the three dry matter intake quartiles discussed, Heat2 shows a trend for larger odds of death.

Conditioning on *Period*, contrasts between quartiles of *DMIPerHeadCateg* are shown in Table 3 B. During Heat1, the odds of death are higher for Q1 (10 lbs) of *DMIPerHeadCateg* than Q3 and Q4. For Heat2, the odds of death are higher for *DMIPerHeadCateg* Q1 when compared individually with Q2, Q3, and Q4. And for the last period, only one contrast is significant. During Heat3, the odds of death are higher for Q1 of *DMIPerHeadCateg* than Q2. A common theme among all periods is cattle consuming less feed tend to have a larger odds ratio of death. This suggests that cattle that are dying have already reduced their intake in an effort to lower metabolic heat load but for some cattle not significantly enough to prevent death.

Table 3: Odds Ratios for *Period* by *DMIPerHeadCateg* Quartiles interactions

A

DMIPerHeadCateg	Period	Period	Odds Ratio	Bonferroni Adj Lower Odds Ratio	Bonferroni Adj Upper Odds Ratio
Q1	Heat 1	Heat 2	0.401	0.023	6.930
	Heat 1	Heat 3	2.236	0.147	33.961
	Heat 2	Heat 3	5.574	0.758	40.990
Q2	Heat 1	Heat 2	0.088	0.005	1.570
	Heat 1	Heat 3	0.969	0.063	15.031
	Heat 2	Heat 3	11.045	1.256	97.169
Q3	Heat 1	Heat 2	0.019	0.002	0.219
	Heat 1	Heat 3	1.007	0.019	54.266
	Heat 2	Heat 3	51.629	1.058	>999.999
Q4	Heat 1	Heat 2	0.029	0.004	0.224
	Heat 1	Heat 3	1.536	0.010	238.850
	Heat 2	Heat 3	53.579	0.320	>999.999

B

Period	DMIPerHead Categ	DMIPerHead Categ	Odds Ratio	Bonferroni Adj Lower Odds Ratio	Bonferroni Adj Upper Odds Ratio
Heat 1	Q1	Q2	11.579	0.253	530.222
	Q1	Q3	56.046	1.764	>999.999
	Q1	Q4	47.286	2.120	>999.999
	Q2	Q3	4.840	0.166	141.521
	Q2	Q4	4.084	0.208	80.230
	Q3	Q4	0.844	0.050	14.160
Heat 2	Q1	Q2	2.533	1.453	4.416
	Q1	Q3	2.724	1.739	4.265
	Q1	Q4	3.379	2.046	5.580
	Q2	Q3	1.075	0.601	1.925
	Q2	Q4	1.334	0.697	2.553
	Q3	Q4	1.240	0.731	2.104
Heat 3	Q1	Q2	5.018	1.554	16.210
	Q1	Q3	25.227	0.873	728.964
	Q1	Q4	32.476	0.185	>999.999
	Q2	Q3	5.027	0.130	194.857
	Q2	Q4	6.471	0.035	>999.999
	Q3	Q4	1.287	0.003	623.749

Next, the results for the interaction between Period and *DMIDailyChange* quartiles are explored in Table 4 A. When *DMIDailyChange* is in Q1 (-11 lbs), the odds of death are significantly higher for Heat2 than Heat1 (Heat1 vs. Heat2 Upper Odds Ratio = 0.253<1) and Heat3 (Heat2 vs. Heat3 Lower Odds Ratio = 3.471>1). *DMIDailyChange* values in Q1 correspond to decreases in feed intake. Figure 2 shows a sharp decline in median dry matter intake during a large median CCI value on July 17 within period Heat2. Hence, these results are an indication that hot weather conditions during July 16 – 18 are associated with the odds of death. Similarly, *DMIDailyChange* in Q2 (-0.10 lbs) shows a larger odds of death ratio for Heat2 than Heat1. Once again, Heat2 stands out. When comparisons are made within period (Table 4 B), only two contrasts for *DMIDailyChange* are significant. During Heat2, the odds of death are higher for Q3 and Q4 (0.35 and 7 lbs) of dry matter intake change than Q1. Q3 and Q4 correspond to increases in feed intake. This result suggests cattle consuming larger quantities of feed during Heat2 are less affected by the heat stress and have larger odds of surviving the harsh weather conditions.

Table 4: Odds Ratios for *Period* by *DMIDailyChange* Quartiles interactions

A

DMIDaily Change	*Period*	*Period*	Odds Ratio	Bonferroni Adj Lower Odds Ratio	Bonferroni Adj Upper Odds Ratio
Q1	Heat 1	Heat 2	0.016	0.023	6.930
	Heat 1	Heat 3	1.927	0.037	100.990
	Heat 2	Heat 3	119.339	3.471	>999.999
Q2	Heat 1	Heat 2	0.087	0.012	0.642
	Heat 1	Heat 3	2.063	0.092	46.161
	Heat 2	Heat 3	23.855	0.879	647.736
Q3	Heat 1	Heat 2	0.126	0.010	1.607
	Heat 1	Heat 3	1.205	0.085	17.132
	Heat 2	Heat 3	9.592	0.619	148.635
Q4	Heat 1	Heat 2	0.112	0.003	4.404
	Heat 1	Heat 3	0.699	0.014	33.851
	Heat 2	Heat 3	6.237	0.537	72.491

B

Period	*DMIDaily Change*	*DMIDaily Change*	Odds Ratio	Bonferroni Adj Lower Odds Ratio	Bonferroni Adj Upper Odds Ratio
Heat 1	Q1	Q2	0.035	0.015	8.045
	Q1	Q3	0.362	0.012	11.031
	Q1	Q4	0.355	0.003	41.665
	Q2	Q3	1.034	0.096	11.197
	Q2	Q4	1.012	0.018	56.505
	Q3	Q4	0.979	0.012	77.761
Heat 2	Q1	Q2	1.877	0.956	3.684
	Q1	Q3	2.820	1.106	7.190
	Q1	Q4	2.463	1.835	3.305
	Q2	Q3	1.502	0.474	4.759
	Q2	Q4	1.312	0.657	2.618
	Q3	Q4	0.873	0.330	2.311
Heat 3	Q1	Q2	0.375	0.007	19.919
	Q1	Q3	0.227	0.008	6.464
	Q1	Q4	0.129	0.007	2.531
	Q2	Q3	0.604	0.028	13.257
	Q2	Q4	0.343	0.021	5.505
	Q3	Q4	0.568	0.103	3.138

Lastly, the interaction between *PenDailyAvgWeight* quartiles and S*qFtPerHead* quartiles are presented in Table 5. When S*qFtPerHead* is in Q2 (190 ft^2), the odds of death are significantly higher for quartiles of *PenDailyAvgWeight* Q2, 3, and 4 (900, 1040, and 1240 lbs) than Q1 (670 lbs). For Q3 (240 ft^2) of *SqFtPerHead* , the odds of death are higher for quartiles of pen average weight Q3 and 4 than Q1. Finally for *SqFtPerHead* in Q4 (1350 ft^2), the odds of death for *PenDailyAvgWeight* of Q4 is higher than Q1. A common observation among the square feet areas considered, heavier cattle have larger odds of death than lighter cattle. Hence, heavier cattle seem more sensitive to higher energy levels than lighter cattle across the pen densities.

Table 5: Odds Ratios for *PenDailyAvgWeight* quartiles by *SqFtPerHead* quartiles interactions

SqFtPerHead	PenDaily AvgWeight	PenDaily AvgWeight	Odds Ratio	Bonferroni Adj Lower Odds Ratio	Bonferroni Adj Upper Odds Ratio
Q1	Q1	Q2	0.238	0.027	2.106
	Q1	Q3	0.229	0.025	2.096
	Q1	Q4	0.433	0.040	4.742
	Q2	Q3	0.964	0.361	2.569
	Q2	Q4	1.820	0.442	7.498
	Q3	Q4	1.888	0.433	8.233
Q 2	Q1	Q2	0.213	0.050	0.905
	Q1	Q3	0.218	0.050	0.955
	Q1	Q4	0.129	0.027	0.620
	Q2	Q3	1.026	0.331	3.175
	Q2	Q4	0.606	0.173	2.120
	Q3	Q4	0.590	0.176	1.978
Q 3	Q1	Q2	0.065	0.003	1.305
	Q1	Q3	0.015	<0.001	0.277
	Q1	Q4	0.021	0.001	0.363
	Q2	Q3	0.235	0.054	1.016
	Q2	Q4	0.324	0.076	1.380
	Q3	Q4	1.379	0.416	4.569
Q 4	Q1	Q2	0.365	0.014	9.368
	Q1	Q3	0.095	0.006	1.425
	Q1	Q4	0.051	0.005	0.539
	Q2	Q3	0.261	0.015	4.618
	Q2	Q4	0.139	0.011	1.806
	Q3	Q4	0.535	0.090	3.183

Of the comparisons between ration groups, only the contrast between ration 14 and rations 41, 42, and 47 grouped together show some evidence of a difference, Table 6. A p-value of 0.0836 gives weak evidence that the odds of death ratios for ration 14 is greater than combination of rations group 414247. Similarly, the lower endpoint for the 95% confidence interval for the odds ratio is 0.9119 which is close to 1. Both results offer weak evidence of a difference in odds of death ratios. According to the estimated odds ratio, the estimated odds of death are 2.0022 times larger for ration 14 than for the combined ration group 414247.

Table 6: Exploratory analysis on contrasts for *Ration* by *Slope* interactions

Label	Est	Std Err	P-value	Odds Ratio	Lower Odds Ratio	Upper Odds Ratio
Ration_Group 14 vs. 414247	0.6943	0.4011	0.0836	2.0022	0.9119	4.3962
Slope SevW vs. Flat	1.1096	0.4390	0.0116	3.0331	1.2823	7.1744
Slope SevW vs. ME	1.2543	0.4673	0.0073	3.5055	1.4022	8.7637
Slope MNW vs. MW	-1.1055	0.6122	0.0711	0.3310	0.09965	1.0997
Slope MNW vs. Nor	-1.3753	0.7303	0.0598	0.2528	0.06036	1.0584
Slope SevW vs. MNW	1.8286	0.6381	0.0042	6.2252	1.7813	21.7555
Slope MNW vs. Sou	-1.2171	0.6589	0.0648	0.2961	0.08133	1.0778

The simple effects of slope are also analyzed using unadjusted odds ratios. When severe west slope is compared with flat, moderate east, and moderate northwest slopes, the odds of death ratios are all higher for the severe west slopes at the 95% confidence level. Since each of these contrasts has a small p-value, these results present strong evidence of a difference. Finally, comparing moderate northwest slope to each of the moderate west, north, and south slopes, weak to moderate evidence indicates that the odds of death ratio are less for a moderate northwest slope.

In Table 7, S*qFtPerHead* quartiles are compared at a specific pen average weight *PenDailyAvgWeight* quartile. When *PenDailyAvgWeight* is in Q1 (670 lbs), the odds of death ratio are higher for *SqFtPerHead* Q1 and 2 (170 and 190 ft^2) than Q3 (240 ft^2) at the 95% confidence level. Thus, lighter cattle in dense pens indicate a higher odds of death ratio than lighter cattle in spacious pens. Next, when *PenDailyAvgWeight* is in Q 2 (900 lbs), the odds of death ratios are higher for *SqFtPerHead* Q1 (170 ft^2) than Q3 and 4 (240 and 1350 ft^2). Likewise, the odds of death ratio are higher for *SqFtPerHead* Q2 (190 ft^2) than Q3 (240 ft^2) given *PenDailyAvgWeight* is in Q2 (900 lbs). Once more, lighter cattle have a higher odds of death ratio in dense pens than spacious pens. Hence, lighter cattle show a change in deaths according to pen density while heavier cattle do not.

Table 7: Exploratory analysis on contrasts for *PenDailyAvgWeight* quartiles by *SqFtPerHead* quartiles interactions

Label	Est	Std Err	P-value	Odds Ratio	Lower Odds Ratio	Upper Odds Ratio
Avg Weight Q1 & Square Feet Q1 vs. Q3	2.6519	1.2799	0.0384	14.1808	1.1525	174.49
Avg Weight Q1 & Square Feet Q2 vs. Q3	2.2899	1.1108	0.0394	9.8735	1.1179	87.2015
Avg Weight Q2 & Square Feet Q1 vs. Q3	1.3512	0.5322	0.0112	3.8621	1.3601	10.9663
Avg Weight Q2 & Square Feet Q1 vs. Q4	1.8865	0.9549	0.0483	6.5960	1.0139	42.9093
Avg Weight Q2 & Square Feet Q2 vs. Q3	1.1010	0.5491	0.0451	3.0070	1.0245	8.826

4. Conclusion

After obtaining the full data set, descriptive statistics summarized availability of information for certain variable levels. Some interactions did not have pens at certain levels and confounding was noticeable. Then, a statistical model was developed and odds ratio confidence intervals were computed for statistical inference. The Bonferroni adjusted odds ratios show low dry matter intake levels have significantly higher odds of death than other levels during July 16 – 18.

Likewise, declines in dry matter intake indicated higher odds of death than when dry matter intake levels were increasing during July 16 – 18. Moreover, when pen area increases, the odds of death are greater for the heaviest pens of cattle than for the lightest pens of cattle. The exploratory data analysis showed the estimated odds of death are 2 times larger for the heifer finisher ration than for the combined Beta-agonist rations. The severe west slope shows evidence of higher odds of death than each of the following slopes: flat, moderate east, and moderate northwest. Finally, odds of death are higher for lighter cattle in dense pens than spacious pens.

5. Summary
This study investigates factors during a heat wave in addition to temperature, which could have an effect on summer feedlot deaths for a single location over a 2 week period in 2010. Descriptive statistics were used to understand the structure of the feedlot data. A generalized linear mixed model was developed based on the significant factors. Additionally, exploratory analyses were applied to further understand the interactions between factor levels.

Factors contributing to cattle deaths, such as daily pen, cattle, and feed type traits, were recorded at a single Midwestern feed yard in July 2010. Weather data were obtained from the feed yard and a neighboring town about 4 miles away. Rather than using multiple weather variables, a single comprehensive climate index that summarizes several weather variables was used to capture the apparent feel of the weather.

Descriptive statistics were obtained to identify whether or not the data set contained pens for each level of the factors and two-way interactions, before constructing a statistical model. Interactions with missing pens were not included in the statistical model due to insufficient information. To improve the structure of the data, days were grouped into three periods: pre-,during, and post-heatwave; pen slope was characterized as flat, moderate (east, northeast, northwest, west), north , severe west, and south; and feed type traits were categorized based on type of ration and dietary feed additive.

A generalized linear mixed model was built using those variables and two-way interactions with adequate pen and death counts. The Bonferroni adjusted odds ratios from the model show pens with lower feed consumption are associated with more deaths. Dry matter intake per head and pen area (ft^2/head) are also associated with cattle deaths. For dry matter intake, the odds of death are higher when intake is declining. Increasing pen space/animal decreased deaths in lighter weight groups but not in heavier cattle.

Exploratory data analysis uses unadjusted odds ratios to provide more insight into the data. Ration and slope are additional factors associated with feedlot deaths. Weak evidence indicates that the heifer finishing ration has larger odds of death than rations containing Beta-agonists. Hence, the Beta-agonists were not found to be associated with cattle deaths. However, the topology of the pen is an important factor. There is strong evidence a severe west slope is a factor contributing to summer feedlot deaths.

Because the feedlot data were not obtained by an experimental design, many difficulties arise. As indicated above, confounding is present within the data set. Thus, definitive hypotheses cannot be tested with these data. Nonetheless, relevant information can still be obtained. More deaths

for rations containing Beta-agonists are needed in order for these rations to be analyzed individually. Further research at another location using these rations with abundant deaths would provide more information as to whether the above tendencies hold.

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