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David Brown

Logo Design
Ruth Cronje, and Jan Swanson;
based on the original design by Dr. Robert Dunlop

Population and truck level factors involved in in-transit death of finishing pigs in Ontario in 2001 and 2004

Charles Haley, DVM, MS, Cate Dewey, DVM, PhD, Tina Widowski, PhD, R.M. Friendship, DVM, MSc
University of Guelph, Guelph, Ontario

Introduction

The term in-transit loss refers to the market weight pigs that die on the way to the packing plant or while they are in lairage at the packing plant. Although the percentage of pigs that die in transit is low, the overall numbers of pigs affected in North America is high.[1,2] This problem represents a significant welfare concern for the swine industry.[3,4] The purposes of this study were to describe the losses experienced by pigs in Ontario and to identify factors that were associated with these losses.

Materials and methods

Data pertaining to all pigs shipped in Ontario in 2001 was obtained from the Inter Transit Loss Account (ITLA) department of Ontario Pork. This data set contained information on shipments of pigs by date for producers, transporters, and packing plant involved as well as if deaths occurred and where they occurred. Hourly dry bulb temperature and humidity were obtained from Environment Canada for the nearest weather station to each packing plant. A distance traveled by the load was assigned based on the road distance from transporter address or assembly yard to the packer address as given by Mapquest(via postal codes. Further calculations for temperature humidity indexes were done using two separate formulae developed for humans and for swine according to a paper by Hahn et al. 2003. These indexes are similar to a humidex and indicate the environmental impact of the combination of temperature and humidity on thermal comfort. The ITLA data was then combined with the distance and weather information using the combination of transporter and packer codes through a sort and merge command in SAS.(

Summary statistics were generated using Excel" and STATA" software. The primary goals of the summary statistics were to analyze potential risk variables for losses (e.g. pig deaths) at the level of the original producer, trucker and packer.

The in-transit loss ratio was calculated as the number of pigs that died in transit divided by the number of pigs marketed by a producer in a day. A Negative Binomial model using backward elimination was used to identify fixed effects associated with the in-transit loss ratio based on a 5% significance level (using STATA). Fixed effects available to the model were dry bulb temperature (in the form of hierarchical dummy variables as per Walter's technique), humidity, total shipped in 2001 by each producer (as an indicator of farm size), mileage (approximate distance the pigs traveled by truck on the day of shipment), and interaction terms consisting of dry temperature ranges and humidity. These variables were then placed in a mixed model using three levels of random effects: producer, trucker, and packer using both the Glimmex macro in SAS and the Gllamm command in STATA. Both programs base their calculations on a Poisson distribution. Additionally, two separate models using the Human Temperature Humidity Index and the Swine Temperature Humidity Index (Pig Comfort Index), respectively, in place of the dry bulb temperature and humidity were examined.

A second series of studies looked at actual environmental conditions on nine trucks and how they contributed to death. The protocol will not be described here but is available upon request.

Results from the population study for 2001

There were 4159 producers, 33 packers and 117 transport companies in this database that were involved with shipping in the year 2001. Market pigs were shipped 329 days out of 365 in the year 2001, and a total of 4,760,213 market weight pigs were shipped in that time with up to 842 being shipped in one shipment by a producer. Twelve percent of the transport companies ship 64% of all of Ontario's pigs. The total losses suffered in 2001 was 7969 or 0.17% of the total shipped. Death losses occurred at each level of shipping (producer, transporter, and packer) indicating that there is a hierarchical or partially nested structure to the Ontario pork industry.

Producers who ship less than 2,000 pigs (assigned as a general cut off based on 1145 pigs shipped on average and a standard deviation of 2032 pigs shipped in Ontario in 2001.) have higher ratios of death compared to producers that shipped more than 2,000 pigs in 2001. Within the producers that shipped less than 2,000 pigs, the greatest dead/shipped expressed as a percentage were observed for producers that shipped less than 100 pigs in 2001. Approximately 65% of producers shipped less than or equal to 500 pigs in 2001.Over 75% of those producers who lost pigs, lost five or less in 2001. No such pattern with a cut off number of pigs shipped or received exists at either the transporter or packer level.

The conditions of transport in terms of weather, and distance traveled were summarized. Dry temperatures seldom went above 30º C in the summer months of June, July, and August, and the maximum temperature was in June (33º C). Humidity in the winter and fall were generally higher (73.8%) than in the summer months (64.1%). Based on the formulas in the Hahn et al. paper, August 2001 was the most uncomfortable month on average for both finishing pigs (22.1) and humans (70.5). As would be expected, death was also greater in the summer months with the highest levels again in August. In that month, 1,617 pigs died.

The approximate distance traveled by transporters to the 34 packers was summarized. Approximately 74% of all shipments to packers involved a distance greater than 200 km. For the distances that Ontario hogs were shipped in this study, distance alone did not have an effect on deaths.

The negative binomial fixed effects model generated a series of covariates to place in a Poisson general linear mixed random effects model (Glimmex)-using producer as the lowest level of potential clustering and packer as the highest level. The Incidence Rate Ratios (IRR) for each fixed effect from the Glimmex model is summarized in **Table 1**. The IRR for each factor generally states how much the Incidence Rate for pig deaths (number of pig deaths/ number of pigs exposed to that factor in time units) goes up by the coefficient's amount when the factor increases by one unit or is in the index range as compared to the range below it.

For the Pig Comfort Index (PCI) hierarchical ranges, the incidence rate for pig deaths within that range is approximately the coefficient times the incidence rate for pig deaths in the range below it. For example, for the first range, the incidence rate for pig deaths between indexes of 10 to less than 14 is approximately 1.13 times greater than the incidence rate for pig deaths in below that range

Table 1: Factors associated with in-transit loss ratio for Ontario market pigs in 2001, with impact measured as incidence rate ratio based on a Poisson general linear mixed random effects model.

Random effect	**Variation due to random variables**	**Standard error**	**P-value**
Producer[A]	0.54	0.029	<.0001
Transporter[A]	0.17	0.044	<.0001
Packer[A]	0.35	0.132	.0042
Error term	1.08	0.004	<.0001

Fixed effect	**Incident Rate Ratio[B]**	**Standard error**	**P-value**	**Predicted Loss[D]**
PCI[C]: 10 to <14	1.13	0.203	<.0001	0.0007
PCI: 14 to <16	1.25	0.046	.0105	0.0008
PCI: 16 to <19	1.24	0.064	.0004	0.0011
PCI: 19 to <22	1.56	0.061	.0003	0.0016
PCI: 22 to <26	1.26	0.048	<.0001	0.0021
PCI: 26 to <32	2.06	0.044	<.0001	0.0043
PCI: 32 to <33	1.48	0.046	<.0001	0.0063
PCI: 33 to 33.6	0.13	0.122	.0014	0.0008
Pigs marketed in 2001 in 500 pig increments	1.02	0.357	<.0001	N/A
(Pigs marketed in 2001 in 500 pig increments)^2	1.00	0.014	.2118	N/A
(Pigs marketed in 2001 in 500 pig increments)^3	1.00	0.001	.0213	N/A
Distance in 50 km increments	1.13	<0.001	.0109	N/A
(Distance in 50 km increments)^2	1.00	0.031	.0001	N/A

[A] Producer, transporter and packer were included in the model as random variables.
[B] The Incidence Rate Ratio (IRR) states that if the index is within that range the Incidence Rate for death is approximately the IRR times the incidence rate of death for the range below it.
[C] The Pig Comfort Index (PCI) is a weighted average of dry temperature (75%) and humidity (25%) (Hahn et al. 2003).
[D] The Predicted loss is calculated by setting relevant indexes to one and the continuous variables to their mean values.

when controlling for all other fixed covariates in the model and the average random effects of producer, transporter, and packer. For the continuous variables the interpretation is somewhat different. The incidence rate for pig deaths goes up by the coefficient if there is a one-unit increase in that covariate. Adding the hierarchical ranges shows that the incidence rate for pig deaths between indices of 10 and 32 (12 to ~33.6°C at 100% humidity) is approximately 8.5 times greater than the incidence rate for pig deaths in indices below that range (**Table 1** and **Figure 1**).

The total variance that could not be explained by fixed effects was 2.14. The highest level of variance based on the clustering of pigs was at the producer level (Intercept

Figure 1 Incremental increases in Pig Comfort Index,[A] as measured by Incidence Rate Ratio (IRR), associated with the ratio of in-transit deaths to those marketed per producer per day in Ontario in 2001.

Pig Index IRR	**DT**	**Humidity percentage**																			
		5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
Ref. Group	**10**	8	8	8	8	8	8	9	9	9	9	9	9	9	9	9	10	10	10	10	10
	11	9	9	9	9	9	9	9	10	10	10	10	10	10	10	10	11	11	11	11	11
1.13	**12**	10	10	10	10	10	10	10	11	11	11	11	11	11	11	11	12	12	12	12	12
	13	10	11	11	11	11	11	11	11	12	12	12	12	12	12	12	13	13	13	13	13
	14	11	11	12	12	12	12	12	12	13	13	13	13	13	13	13	14	14	14	14	14
	15	12	12	13	13	13	13	13	13	14	14	14	14	14	14	14	14	15	15	15	15
	16	13	13	13	14	14	14	14	14	14	15	15	15	15	15	15	15	16	16	16	16
1.25	**17**	14	14	14	15	15	15	15	15	15	16	16	16	16	16	16	16	17	17	17	17
	18	15	15	15	15	16	16	16	16	16	17	17	17	17	17	17	17	18	18	18	18
1.24	**19**	16	16	16	16	17	17	17	17	17	17	18	18	18	18	18	18	19	19	19	19
	20	17	17	17	17	18	18	18	18	18	18	19	19	19	19	19	19	20	20	20	20
	21	18	18	18	18	18	19	19	19	19	19	20	20	20	20	20	20	21	21	21	21
	22	18	19	19	19	19	20	20	20	20	20	21	21	21	21	21	21	22	22	22	22
1.56	**23**	19	20	20	20	20	20	21	21	21	21	22	22	22	22	22	22	23	23	23	23
	24	20	20	21	21	21	21	22	22	22	22	22	23	23	23	23	23	24	24	24	24
	25	21	21	22	22	22	22	23	23	23	23	23	24	24	24	24	24	25	25	25	25
1.26	**26**	22	22	23	23	23	23	24	24	24	24	24	25	25	25	25	25	26	26	26	26
	27	23	23	23	24	24	24	24	25	25	25	25	26	26	26	26	26	26	27	27	27
	28	24	24	24	25	25	25	25	26	26	26	26	27	27	27	27	27	27	28	28	28
	29	25	25	25	26	26	26	26	27	27	27	27	27	28	28	28	28	28	29	29	29
	30	25	26	26	26	27	27	27	28	28	28	28	28	29	29	29	29	29	30	30	30
2.06	**31**	26	27	27	27	28	28	28	28	29	29	29	29	30	30	30	30	30	31	31	31
	32	27	28	28	28	29	29	29	29	30	30	30	30	31	31	31	31	31	32	32	32
	33	28	28	29	29	29	30	30	30	31	31	31	31	32	32	32	32	32	33	33	33
	34	29	29	30	30	30	31	31	31	32	32	32	32	33	33	33	33	33	34	34	34
	35	30	30	31	31	31	32	32	32	33	33	33	33	34	34	34	34	34			
	36	31	31	32	32	32	33	33	33	33	34	34	34								
1.61	**37**	32	32	32	33	33	33	34	34	34											
	38	32	33	33	34	34	34														
	39	33	34	34								Outside Range of Model									
	40	34																			

[A] The Pig Comfort Index (PCI) is a weighted average of dry temperature (DT) (75%) and humidity (25%) (Hahn et al., 2003). These models were developed using a Glimmex macro in SAS (PC/SAS version 8.2) and included pigs shipped in 500 pig increments by the producer for 2001 (in linear, squared and cubic terms) and distance traveled to market in 50 kilometer increments (in linear and squared terms) as fixed effects and producer, transporter and packer as random variables. The Pig Comfort Index IRR is the incidence rate ratio increase expected for each category compared to the category above it in the figure. These IRR are additive, so that the 3rd category from the top has an IRR of 2.38 times that of the referent group. Ref. Group is the reference group to which the second category is compared. This Pig Comfort Index **Figure 1** includes the temperature used to determine the index. The temperature is in the second column and it is ranging from low to high from the top to the bottom of the figure. The humidity is across the top. It illustrates the influence of temperature at various levels of humidity. This figure suggests that pigs experience extremely high losses if they are shipped at temperatures of 33° C or above with a humidity of 90%. Similarly high losses are experienced by pigs shipped at 34° C if the humidity is above 65% or 35°C if the humidity is above 45% (Pigindex >33). Pigs experience high losses if they are shipped at 27°C when the humidity is 90% or 29°C if the humidity is 40%(Pigindex of 27 to 32). Finally, pigs experience relatively high loss ratios if they are shipped at 23°C if the humidity is 85% or at 26° C if the humidity is 35%, or 15% (Pigindex of 23-26). The information will be made available to the swine industry because it will enable producers, transporters, and packers to make valid shipping decisions based on environmental conditions and transportation factors experienced in Ontario.

estimate= 0.54 or 25%), slightly lower within the packer level (Intercept estimate= 0.35 or 16%) and lower still within the transporting company level (Intercept estimate= 0.17 or 8%). This means that the origin of most of the losses that could not be accounted for by factors in the model lay somewhere in circumstances surrounding the farm of origin.

Results from the truck study for 2004

All nine trucks were there-tier possum bellies and had temperature sensors placed in three locations and monitored over 104 trips from July to October 2004. The trailer conditions were similar between the top and back compartments and also between the bottom and back compartments. The original dataset of truck conditions was longitudinal in nature (e.g. observations in time series or repeated measures). However, the average temperature in the bottom compartment was 1.8ºC higher than in the top compartment ($p<0.019$) and the maximum temperature on a trip was 1.5ºC higher in the bottom than in the top. Temperatures ranged from 4.9 in the back position to nearly 40ºC in the top position and humidity from 24.2 in the bottom position to 100% in all positions. The average humidity for all trips was 66.3%, 57.7% and 64.9% for the top, bottom and back locations respectively. For the purposes of analysis as either a dependent or independent variable, the recordings in the three locations were averaged for each point in time.

Average dry temperature within the 9 trucks over the study period ranged from 2ºC to 36ºC and average humidity ranged from 23.6 to 99.43%. The pigs were exposed to temperatures of less than 28.9ºC and humidity of less than 80.4% for 90% of the time measured by all of these trips. When a truck was stopped to either load pigs or waiting to unload them maximum temperatures for the stop were reached in approximately 5 minutes on average.

Conditions inside the trailer were associated with external factors. As the external temperature increased, the internal temperature increased (**Table 2**). A 1ºC increase in external temperature was associated with a 0.99ºC increase in trailer temperature. Similarly, a 1% increase in humidity was associated with a 0.11ºC increase in trailer temperature (**Table 2**). Environmental temperature, humidity and the interaction of these factors were related to internal truck temperature. Predicting the average internal temperature depended upon the level of humidity between approximately 7.3 and 24.1ºC but not at temperatures between approximately 24.1 and 26.5ºC (**Figure 4**). Interestingly, at an environmental temperature of 26.5ºC, the temperature and humidity together converged to create nearly identical dry temperature conditions inside and outside the truck (**Figure 4**).

The distance traveled between observations was associated with a reduction in trailer temperature. As distance increased by 1 km increments, trailer temperature decreased by 0.41ºC. There was a curvilinear relationship between distance traveled and the internal truck conditions (**Table 2** and **Figure 2**). The temperature decreased 0.33ºC between 0.83 and 3.26 km (**Figure 2**).

Table 2: Factors associated with average dry temperature and humidity in trucks[A] transporting market pigs in Ontario in the summer of 2004.

Random effect	Variation	SE	P
Transport company	NS[b]	NS	NS
Truck	0.77	0.613	0.1054
Trip	3.81	0.565	<.0001
Error term	7.25	0.045	<.0001

Fixed effect	Coefficient	SE	P
Intercept	-5.06	0.629	<.0001
Distance (km)	-0.41	0.023	<.0001
$(\text{Distance})^2$	0.06	0.008	<.0001
$(\text{Distance})^3$	-0.002	0.0003	<.0001
Pigs/m^2	0.59	0.306	0.055
$(\text{Pigs/m}^2)^2$[C]	0.92	0.092	<.0001
Environmental temperature	0.99	0.018	<.0001
Environmental humidity	0.11	0.005	<.0001
Temp*Humidity	-0.004	0.0002	<.0001

[A] Based on the average temperature or average Pig Comfort Index recorded from three locations on the truck during 52,293 one-minute intervals which account for the cumulative distance traveled by 104 trips.
[B] NS=not significant at the 5% level for fixed effects or less than a 0.000001 variation component at the random level.
[C] The cubic form of this term stabilized the model but made the effect of density negative.

Figure 2. Relationship of distance to predicted average internal dry temperature based on the longitudinal model

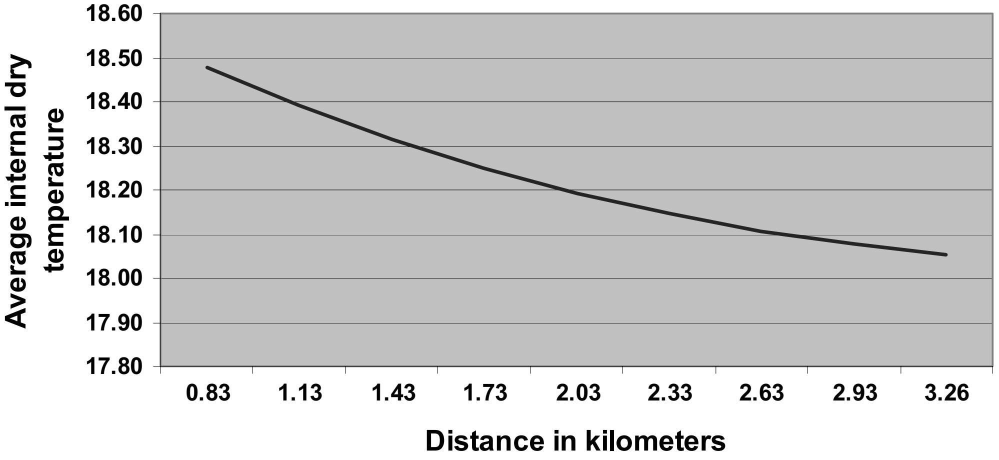


Figure 3. Relationship of pig density in meters squared to predicted average internal dry temperature based on the longitudinal model.

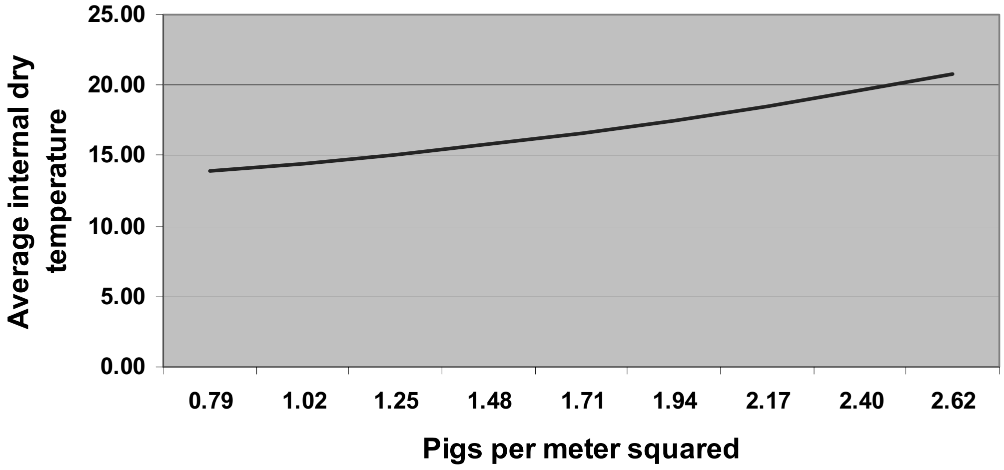
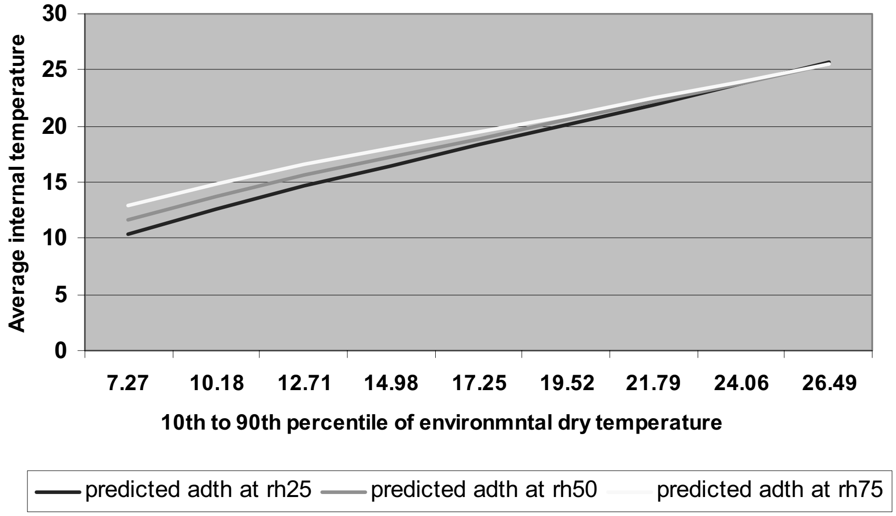


Figure 4. Relationship of the interactive effects of external dry temperature and humidity on the average internal dry temperature in the longitudinal model



The maximum pig density on these trailers ranged from 1.78 to 3.23 pigs/m^2. At an average shipping weight in Ontario of 114 kg, this meant that these trips ranged from 202 to 368 kg/m^2. As the pigs/m^2 increased by 1 unit increments, the trailer temperature increased by approximately 0.6°C. This is better expressed by the significant quadratic relationship between pig density and temperature (**Table 2** and **Figure 3**). There was a curvilinear relationship between pig density as measured by pigs/meter squared and the internal truck temperature (**Figure 3**). An increase in density from approximately 1 to 2 pigs/m^2 was associated with a 3°C increase in temperature. Between 2 and 2.6 pigs/m^2, the temperature increased a further 4°C.

Trip number represented 32% of the unexplained random variation in internal truck temperature. The truck used explained only 7% of the unexplained random variation in temperature (**Table 2**). The trucking company was not associated with internal temperature. This model with fixed effects alone explained 62% of the variation in average internal temperature.

In the second part of this study these 104 trips were collapsed from a longitudinal dataset to one where the number shipped by a producer on a given day was the unit of concern, which reduced the number of observations from approximately 52,000 to 654 observations (one for each producer within each trip). These trips took 21,834 pigs to the abattoir. Modelling previously used average internal temperature as a continuous outcome while modelling here used count data as in the population study and death during transit expressed as a rate as the outcome and average internal temperature as an independent variable. Model building was guided by two general hypotheses. The first was that internal temperature would be a far better predictor of death (e.g. render most other variables insignificant when modeled with them) than those used in the population study. This would be primarily because both external conditions and density on the truck would be explanatory antecedents to internal truck conditions. The second was that expressing internal conditions as the 90th and 50th percentiles of average internal conditions on a trip would keep some of the longitudinal nature of this variable. That is, express internal conditions by a number that summarises what is the maximum temperature a pig could be exposed to over 90 or 50% of the time in a trip. This places time consideration on both sides of a Poisson or Negative Binomial general linear equation.

On average in-transit loss for the producers was 0.12% of all pigs shipped. However, 90 % of producers experienced no losses and the maximum loss was six pigs from one producer in one transport. Only 21 producers of the 370 producers lost pigs on these 104 trips. Although the average pig density was 2.52 pigs/m^2, this ranged from 1.78 pigs/m^2 to 3.23 pigs/m^2.

On average, the 90th and 50th percentiles of temperature in the trucks were 26.3 and 22.9 °C respectively. Within truck temperature was associated with in-transit loss (**Table 3**). As temperature increased losses also increased. Once again Incident Rate Ratios (IRR) were used in each of the multivariable models to express the effect of each of the fixed of variables upon death in-transit. In general, an IRR of greater than one means a factor contributes to death and less than one indicates a sparing effect on death.

Table 3: Factors associated with in-transit losses based on the 90th and 50th percentiles of average internal truck temperature for 104 loads of Ontario market pigs in 2004

	Percentile of temperature[A]					
	90th			**50th**		
Random effects	**Value**	**SE**	**P**	**Value**	**SE**	**P**
Trip number	4.42	0.931	<.0001	4.72	0.981	<.0001
Error Term	0.22	0.013	<.0001	0.22	0.013	<.0001
Fixed effects	**IRR**[B]	**SE**	**P**	**IRR**[B]	**SE**	**P**
Intercept	0.00	2.247	<.0001	0.00	1.973	<.0001
Temperature[A]	1.24	0.081	0.010	1.25	0.082	0.007
Trip time total/165[C]	0.51	0.138	<.0001	-	-	-
Distance in 50 km increments	-	-	-	0.81	0.045	<.0001
n	654			654		

[A] The temperature is the average internal dry temperature measured from three areas on the truck measured as the 90th and 50th percentiles for the two models respectively.

[B] The Incidence Rate Ratio (IRR)states that if the factor goes up by one unit the Incidence Rate for death is approximately the IRR times the incidence rate of death when the factor does not go up by one unit.

CTotal Trip Time in minutes divided by the smallest trip time in minutes as a standardized variable to increase coefficient value.

More specifically, these ratios indicate the increase or decrease in the incident rate of deaths (number of deaths/ number of animals that could have died expressed in time units) for every single increment increase in the factor measured. As the 90th or 50th percentiles of temperature within a trip increased by one degree Celsius the incident rate of death was expected to increase 1.24 or 1.25 times, respectively (**Table 3**).

The length of the trip measured either by distance in 50 km. increments or by duration of trip in 165 minute increments were associated with a reduction in in-transit loss by 0.81 or 0.51 times respectively in the temperature percentile models (**Table 3**). No other variables considered (humidity on the trucks, pig density (pigs/m^2), average of maximum speeds in trips, average of average speeds in trips, total number of stops in a trip greater than or equal to 10 minutes and the numbers of pigs shipped by individual producers in 2004 as a measure of farm size) were associated with in-transit loss after controlling for temperature and trip time or distance (**Table 3**).

Of the random variables, neither the truck driver nor the transport companies were associated with in-transit losses. However, trip number was significant and explained 96 to 98 % of the variation not accounted for by fixed effects (**Table 3**). These models with fixed effects alone explained approximately 17 to 20% of the variation in death.

Take-home messages

- Pigs are affected by both temperature and humidity
- Reductions in density of pigs on trucks must take both heat and humidity into account
- Farm of origin accounts for more variation due to in-transit loss than does transport company or packing plant
- Producers must implement changes in genetics or handling or feeding practices to reduce in-transit losses
- Pigs in the target population travelling large distances did not experience higher in-transit losses than those travelling shorter distances
- Since the "belly" area of the truck does not appear to be ventilated during motion along with the rest of the truck this type of truck design should be phased out in favour of straight trucks when shipping pigs.
- A pigs Upper Critical Temperature (UCT-where a pig must begin to cool themselves actively or begin hyperthermia) is affected by many factors but in- transit most by density.
- The UCT is estimated to be as low as 23ºC (73ºF).
- Reducing the pig density during hot weather conditions is imperative to prevent significant additional heat that is generated by the pigs themselves.
- Using the internal temperature or an index on a truck in percentiles as a predictor of in-transit death appears to be a stronger variable than external conditions and density on a truck.
- Temperature and humidity sensors are relatively inexpensive and could be used on trucks throughout North America for a fraction of the cost both financial and from a welfare standpoint of dead pigs.
- Using a readout in the cab of livestock transporters could provide drivers with information as to when trailer temperatures are too high. A combination of sprinklers and fans could then be turned on to cool pigs.
- Ship at night?

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