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Impact of trailer design factors on conditions during transport

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Introduction

Loss of slaughter pigs during transport to the plant [dead on arrival (DOA), non-ambulatory, injured (NAI), and non-ambulatory, non-injured (NANI) animals] continues to be a significant issue for the US swine industry, representing both a substantial economic loss and, also, a major animal welfare concern. Some studies have shown a link between the incidence of DOA and NANI pigs (Hamilton et al., 2003), suggesting some common causal factors. Metabolic acidosis resulting from the combination of stress and exercise during the transportation process has been implicated as a major factor involved in the development of NANI pigs (Benjamin et al., 2001; Anderson et al., 2002). Metabolic acidosis is observed in pigs that are stressed during transportation, particularly as a result of factors such as bad handling practices during loading, and reduced floor space allowances and mixing of pigs from different farm groups on the trailer.

However, we have observed a significant incidence of NANI pigs in situations where the animals were handled optimally during loading at the farm. Presumably such animals experienced some stressful conditions during the journey that led to the NANI condition. However, our understanding of the conditions experienced by pigs on the trailer during transport is extremely limited. The micro-climate that pigs are exposed to during transport is likely to have a large impact on the stress levels experienced by the animal and, therefore, on the incidence of NANI pigs. Major environmental factors that are involved in determining the micro-climate in the trailer include temperature, humidity, air speed, air pressure, gas levels, and the amount and condition of any bedding.

Mitchell and Kettlewell (1998) found that the major stressor on poultry in transit was the thermal micro-environment and the same is likely to be true in pigs. High environmental temperature results in elevated body temperature which predisposes the pigs to the NANI condition. In support of this, field data has suggested a higher incidence of DOA and NANI pigs during the summer months (Hamilton, unpublished). However, the incidence of transport losses can also be high under cold conditions (Hamilton, unpublished; Ritter et al., 2006). In the winter months, pigs are reared in barns at environmental temperatures generally within their comfort zone and are likely to experience cold stress when loaded and transported under low ambient temperatures. The pigs' response to cold conditions is to increase metabolic rate, thus, predisposing them to developing metabolic acidosis and the NANI condition.

Although the micro-environment experienced by pigs on the trailer during transport is critical for animal well-being and, potentially, impacts transport losses and, ultimately, pork quality, it is poorly understood. This largely reflects the difficulty of measuring the appropriate parameters during transportation. The objective of the study reported here was to measure the environmental conditions on a livestock trailer during transport of harvest-weight pigs under the range of climatic conditions typically experienced in the Midwest of the US. In addition, these results were used to develop a computer simulation model that could be used to develop recommendations for new trailer designs and management of existing trailers to provide the optimum environment on the trailer for finishing pigs.

Materials and methods

This research was a collaboration between faculty at the University of Illinois and scientists from a leading commercial pig production company (The Maschhoffs). The project was carried out in two parts with the first part involving the equipping of a swine transport trailer with measuring equipment to collect data on conditions on the trailer under typical transport conditions. In the second part, these data were used to construct a computer simulation model to predict the environment on the trailer under the range of conditions experienced in the Midwest of the US.

Measurement of conditions on the transport trailer

Monitoring environmental conditions during transport is difficult and requires a unique system that provides accurate data but also has the ability to withstand the harsh physical environment inside the trailer. The main determinants of the internal thermal environment of commercial livestock transport trailers are the external climatic conditions, ventilation regime, internal air flow patterns, and total heat and moisture production of the animals. A conventional straight deck trailer (Wilson Trailer Company; Sioux City, Iowa), owned and operated by The Maschhoffs, was used in this project. This trailer had two decks with five compartments in the top deck and six compartments in the bottom deck; compartment dimensions and areas are given in Table 1.

Measuring equipment

Instrumentation was installed at just above pig level in all compartments to measure temperature, relative humidity, carbon dioxide, and air velocity. In addition, truck speed, ambient temperature and relative humidity, solar radiation, internal surface temperatures in the trailer (in one compartment), and the skin temperatures of the pigs (in two compartments) were also measured. Sensors were protected to prevent damage due to the pig or the environment. They recorded data every six seconds during the transport process (from start of loading through to unloading at the packing plant) and were connected to a single data acquisition system that was installed in a laptop computer that was carried in a box located under the trailer during the journey.

All instruments were tested and calibrated in the laboratory prior to use for any data collection. In addition, several journeys with the trailer empty of pigs were carried out prior to the start of the data collection part of this project to test that all components of the data acquisition and storage system were functioning effectively.

Data collection

Data were collected on environmental conditions on the trailer on a total of 20 loads of pigs on routine journeys under typical transport conditions with finishing pigs loaded at the same standard stocking density in all seasons (spring, summer, fall, and winter). The test was carried out for five days in each season (one load per day for a total of 20 loads). The timing of these loads was selected so that the journeys were carried out under typical conditions for the respective season. The trucks travelled directly from the farm to the plant without any unnecessary stops. Loading and transport protocols were standardized across test loads. The same loading crew was used at each site and pig density on the truck was standardized at 0.36 m^2/100 kg live weight for all journeys, which is typical for this production system.

Prior to each journey, the trailer was set up based on forecasted daily temperature. Sawdust was used as a bedding material on the floor of the trailer and the proportion of the openings in the side of the trailer that were closed were adjusted according to the ambient temperature using the information presented in Table 2 which was derived from the Trucker Quality Assurance Handbook (National Pork Board, 2004).

All measurements were recorded from before the animals were loaded onto the trailer, during the journey, and up to the end of the unloading process at the plant. The process of data acquisition was continuously monitored with a laptop computer to ensure that all sensors were operating properly during the journey. After each journey, data were downloaded from the laptop computer onto a desktop computer for checking and analysis.

Table 1: Dimension and area of the compartments

Compartment	Length, m	Width, m	Floor area, m^2
Top deck			
1	2.98	2.50	7.43
2	3.31	2.50	8.26
3	3.71	2.50	9.25
4	2.08	2.50	5.20
5	3.73	1.33	4.96
Bottom deck			
1	2.98	2.50	7.42
2	3.31	2.50	8.26
3	3.71	2.50	9.25
4	1.98	2.50	4.94
5	3.84	1.31	5.03
6	3.84	1.12	4.29

Results

General

Transport distances and times (start of loading at the farm to end of unloading at the plant) for the 20 loads used for data collection averaged 221 km (range from 95 to 285 km) and 322 min (range from 256 to 375 min). Each load had 156 pigs with an average live weight of 132 kg (range 122 to 137 kg); the average floor space on the trailer of 0.48 m^2/pig, which is equivalent to 0.36 m^2/100 kg live weight, which was the standard floor space used by this system at the time that the study was carried out.

Environmental conditions on the trailer

Means for event times and the temperature and relative humidity on the trailer for the four seasons and the overall study period are presented in Table 3. In general, the event times were typical of those observed within this system with the differences in transport times between seasons reflecting the location of the farms used relative to the plant. As expected, there were large seasonal differences in the temperature on the trailer; also, there was seasonal variation in relative humidity levels, however, this was relatively limited compared to the variation in average compartment temperatures.

Temperature, relative humidity, and air velocity data for the 11 compartments in the four seasons and the overall study are presented in Tables 4, 5, and 6, respectively. The values reported in all three tables are the averages for all loads in each season and are for the measurements taken during the journey only, when each compartment was full of pigs (i.e., excluding loading and unloading and times spent waiting at the farm and the plant). Levels for all 3 measures varied among compartments in each of the four seasons. The number of pigs was the same in each compartment across seasons, but the amount of bedding on the floors and the number of the holes in the trailer sides that were open or closed changed according to the external temperature.

In general, temperature levels in all seasons tended to decrease from the front to the rear of the trailer, with the greatest decreases occurring in the winter season (Table 4). In the summer season, differences in temperature among the compartments were relatively small. In the spring, summer, and fall seasons, the temperature in the compartments on the upper deck generally tended to be slightly higher than in the compartment directly below. This may be due to a combination of heat rising from the bottom to the top deck and also to the incident solar radiation coming through the fiberglass roof of the trailer.

Within season, differences between compartments in relative humidity were relatively small and showed no consistent pattern (Table 5). Relative humidity levels were greater in the winter than in the other three seasons, which were relatively similar.

Air velocities during the journey for the four seasons are presented in Table 6. Top deck compartment 1 and bottom deck compartment 1, which are located at the front of the trailer, and top deck compartment 5 which is located at the rear of the trailer, had some of the lowest values for air velocity in all seasons. Other compartments also had relatively low air velocities in certain seasons. For example, bottom deck compartments 4, 5, and 6 which are located at the rear end of the trailer had low air velocities in the summer. Generally, air velocities in the trailer were higher in the spring and winter than in the summer and fall.

The concentrations of carbon dioxide in the 11 compartments for one of the summer loads (July 13th) are presented in. Carbon dioxide concentrations are an indirect measure of ventilation rate, with higher levels in any compartment indicating lower ventilation rates. The front compartments of the trailer had higher levels of carbon dioxide than the rear compartments. In studies with commercial poultry transport trailers, it has been shown that the air flow within the trailer is from the rear to front with air entering at the back of the trailer and exiting towards the front (Hoxey et al., 1996; Baker et al., 1996). If the same air flow pat-

Table 2: Truck set-up procedures during temperature extremes

Air temperature °C (°F)	Bedding[1]	Side slats[3]
< - 12.2 (< 10)	Heavy	90% closed
-12.2 to -6.6 (10-20)	Medium	75% closed
-6.6 to 4.4 (20-40)	Medium	50% closed
4.4 to 10 (40-50)	Light	25% closed
> 10 (> 50)	Light	0% closed

[1] Heavy = 3 bags/deck; Medium = 2 bags/deck; Light = 1 bag/deck [Each bag contained 0.28 m^3 (10 ft^3) of wood shavings].

[3] Calculated on a basis of 41 total equally-sized panel openings available on the truck

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Table 3: Means for event times, temperature, and relative humidity for the four seasons.

	Season				
Variable	**Spring**	**Summer**	**Fall**	**Winter**	**Overall**
Total number of loads	**6**	**5**	**5**	**4**	**20**
Timing of events, minutes					
Loading	41	62	63	64	56
Waiting at the farm	8	6	8	8	7
Transport	222	197	84	187	174
Waiting at the plant	16	54	58	68	46
Unloading	32	32	42	49	38
Total transport time	319	351	256	375	322
Temperature in the trailer by event, ˚C					
Loading	16.4	29.2	17.8	0.6	17.6
Waiting at the farm	21.2	30.2	20.6	7.8	20.1
Transport	17.1	29.3	19.2	5.6	18.6
Waiting at the plant	20.7	30.7	20.4	6.3	19.1
Unloading	14.3	32.2	21.5	8.0	18.8
Relative humidity in the trailer by event, %					
Loading	46.8	51.0	60.2	62.1	54.4
Waiting at the farm	47.4	56.5	53.5	71.1	55.3
Transport	45.8	47.2	43.9	51.8	47.5
Waiting at the plant	45.1	39.6	43.4	60.0	47.7
Unloading	42.6	42.5	40.7	60.1	47.4

Table 4: Means for temperatures (˚C) in individual trailer compartments for the four seasons and overall.

	Trailer compartment										
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**6**
Deck location	**Top front**	**Top middle**	**Top middle**	**Top middle**	**Top rear**	**Bottom front**	**Bottom middle**	**Bottom middle**	**Bottom middle**	**Bottom rear**	**Bottom rear**
Spring	18.0^{b}	16.9^{c}	16.6^{d}	16.0^{g}	15.9^{h}	19.0^{a}	16.4^{e}	16.2^{f}	15.9^{h}	15.0^{j}	15.6^{i}
Summer	29.4^{e}	30.0^{b}	29.9^{c}	29.9^{c}	29.6^{d}	30.6^{a}	29.2^{f}	29.3^{f}	29.4^{e}	28.7^{g}	29.6^{d}
Fall	21.3^{b}	21.1^{c}	20.5^{d}	19.6^{f}	18.8^{h}	22.3^{a}	19.8^{e}	19.5^{f}	19.2^{g}	19.2^{g}	18.6^{i}
Winter	12.5^{a}	10.4^{c}	6.9^{d}	3.9^{g}	2.9^{i}	11.4^{b}	6.8^{e}	4.8^{f}	3.6^{h}	1.1^{j}	0.7^{k}
Overall	20.3^{b}	19.6^{c}	18.5^{d}	17.3^{g}	16.8^{i}	20.8^{a}	18.1^{e}	17.4^{f}	17.0^{h}	16.0^{k}	16.1^{j}

tern occurs in the trailer used in this study, then the higher carbon dioxide levels at the front could reflect the movement of carbon dioxide from the rear to the front of the trailer and also the low ventilation rates in those compartments.

These results highlight the considerable variation between seasons in environmental conditions on the trailer. In particular, the seasonal differences in temperatures between summer and winter (30.6 to 1.1˚C) represent a range for the animal between heat and cold stress.

As well as this seasonal variation in conditions on the trailer, there was also substantial variation in conditions within each journey, particularly for temperature and especially during the winter. One of the most critical but poorly understood periods of the transportation process is

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Table 5: Means for the relative humidity (%) in individual trailer compartments for the four seasons and overall.

	Trailer compartment										
	1	2	3	4	5	6	7	8	9	10	11
Deck location	**Top front**	**Top middle**	**Top middle**	**Top middle**	**Top rear**	**Bottom front**	**Bottom middle**	**Bottom middle**	**Bottom middle**	**Bottom rear**	**Bottom rear**
Spring	42.8^{e}	40.6^{g}	41.8^{f}	43.0^{d}	43.8^{b}	40.8^{g}	41.8f	43.3^{c}	43.2^{c}	44.3^{a}	43.9^{b}
Summer	46.7^{b}	46.9^{b}	47.3^{a}	46.5^{c}	44.3^{g}	44.2^{h}	45.1e	44.7^{f}	$44.2^{g,h}$	45.4^{d}	$44.2^{g,h}$
Fall	44.5^{d}	45.5^{b}	46.1^{a}	43.9e	$44.7^{c,d}$	43.5^{g}	42.7h	$43.8^{e,f}$	$43.6^{f,g}$	44.9^{c}	$43.7^{f,g}$
Winter	61.8^{a}	58.4^{b}	56.3^{c}	53.1^{e}	53.4^{d}	51.0^{h}	49.8^{j}	51.7f,g	50.4^{i}	51.5^{g}	51.9^{f}
Overall	48.9^{a}	47.8^{b}	47.9^{b}	46.6^{c}	46.5^{c}	44.9^{f}	44.8^{f}	45.8d	45.3^{e}	46.5^{c}	45.9^{d}

Table 6: Mean carbon dioxide concentrations (ppm) for individual compartments for a summer load (July 13th).

Deck compartment	**Top 1**	**Top 2**	**Top 3**	**Top 4**	**Top 5**	**Bottom 1**	**Bottom 2**	**Bottom 3**	**Bottom 4**	**Bottom 5**	**Bottom 6**
Location	Front	Middle	Middle	Middle	Rear	Front	Middle	Middle	Middle	Rear	Rear
Carbon dioxide, ppm	1385^{e}	2746^{a}	1464^{d}	1079^{g}	1195^{f}	2619^{b}	993^{h}	1827^{c}	878^{i}	961^{h}	1101^{g}

Means with differing superscripts differ ($P < 0.05$)

during loading when the trailer is stationary at the farm. This is often the time when the most rapid and extreme temperature changes and also the greatest variations in temperature between compartments occur, particularly under cold conditions. For example, for one load of pigs transported in the winter (February 7th), the temperature in all compartments at the start of the loading process was below -5˚C. Pigs were loaded onto the top deck first and by the time that the truck left the farm approximately 1 hour after the start of the loading process the temperature in the compartments on the top deck had increased to between 12 and 22˚C, with the highest temperatures being for the front compartments. Similarly, the temperature in the front compartment of the bottom deck increased to around 15˚C by the start of the journey. In contrast, the temperature in the rear compartments of the bottom deck, although it increased after the pigs were loaded, remained between 0 and 3˚C at the start of the journey and actually decreased during the journey to the plant. Thus, for winter loads the temperature difference between coldest (rear of bottom deck) and warmest (front of top deck) compartments was around 20˚C compared to 5 to 8˚C for the other 3 seasons.

The pigs used for these loads came from environmentally controlled barns where ambient temperatures are generally held at around 16 to 18˚C. Obviously, the drop in temperature in the winter when the pigs are moved onto the trailer can be extreme and this will represent a substantial thermal stress on the animal. The temperature of the front compartments increased after loading and before the trailer left the farm had reached levels approaching the comfort zone for pigs of the weight used in this study. However, the temperature of the rear compartments, particularly on the bottom deck, were still very low (< 5˚ C) by the time the trailer left the farm and pigs in these compartments would be under considerable cold stress for most if not all of the journey to the plant.

Changes in conditions during the transportation process

As previously discussed, there was considerable variation in conditions on the trailer between seasons. However, the general trends for changes in temperature and humidity levels and air velocity during the transportation process was generally similar, although the magnitude of the change differed for some parameters.

In general, compartment temperatures increased during loading and, also, at times when the trailer was stationary such as during waiting at the plant and unloading, but decreased during the journey when the vehicle was moving. Relative humidity levels generally followed a similar pattern to that of temperature, increasing when the trailer was

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stationary at the farm and the plant and decreasing during the journey. These changes in temperature and humidity levels in the compartments reflected the changes in air velocity within the trailer which was, obviously, relatively low when the trailer was stationary and increased to relatively high levels when the trailer was moving.

Development of the computer model

A three-dimensional Computational Fluid Dynamic model was developed to predict conditions (i.e., the air velocity, and temperature and moisture variations) in all compartments on the trailer based on the data collected during the journeys with the trailer loads of pigs described above. The overall objective of the model was to predict internal environmental conditions in the compartments during a typical journey for a given set of ambient weather conditions, animal densities, bedding types, and sidewall openings. The environmental factors which influence thermal comfort of animals and which were incorporated into the model included dry bulb temperature, humidity, air velocity, floor heat conduction, and trailer roof and wall surface temperatures (for radiation heat exchange). The conclusions and recommendations based on the output from the model as well as the data collected on the trailer loads of pigs are presented below.

Conclusions

- Historically, there has been limited research carried out monitoring the environment for pigs during transport which largely reflects the difficulty of measuring environmental parameters on the trailer during transportation. This project represents the first attempt, in the US at least, to measure those conditions and to develop a computer simulation model to predict the micro-environment for the finishing pig during transport from the farm to the slaughter plant under the wide range of external weather conditions experienced in the US. In common with all other computer simulation models, a number of simplifying assumptions were made in order that a functional model could be constructed.
- Ideally, the accuracy of any model should be tested using a validation step in which data on the micro-environment on the trailer collected during transport from different loads of pigs than those used for model construction is compared with the predictions from the model. Due to constraints on time and funding, this validation step has not been carried out and until such validation has taken place the results from model simulations must be considered with caution.
- Results relating to the measurements taken on the trailer during the data collection phase of the project suggested that:
  - The times of greatest extremes of and changes in temperature within the trailer were when the trailer was stationary either at the farm during loading or at the plant prior to and during unloading. These are times of low air movement within the trailer when there is the greatest potential for pigs to experience thermal stress, due to either too high or too low temperatures, and, obviously, are times when greatest care is needed to prevent problems.
  - Although heat stress during transport can be a significant problem for pigs, particularly in the summer, the data collected during the winter suggests that cold stress could also be an issue. The variation in temperature between the compartments was also greatest in the winter, suggesting, substantial localized differences in cold stress within the same trailer load of pigs.
  - Temperatures were generally higher in the front compartments compared to other locations which reflect the probable direction of air flow within the trailer (from rear to front) as well as the lack of air movement in the front compartments. Increasing ventilation in the front compartments (for example, by installing a fan in the front of the trailer shell) would obviously increase ventilation rates and could reduce temperature stress under hot conditions.

Suggestions for improved trailer design and management

- Given the extremes of weather that are experienced in the US, it is unlikely to be practically possible or economically feasible to design trailers for transporting pigs that provide the optimum environment for the pigs for all weather conditions. However, the data collected during this study and the model simulations based on those data highlighted the considerable variation in environmental conditions on the trailer both between seasons and, within season, between different locations on the same trailer load of pigs. The recommendations outlined here are practical approaches aimed at reducing this variation in the micro-environment for the pigs on the trailer.
- With current designs of trailers, such as the one used in this study, the openings in the side walls are identical for all compartments. Ideally, the size, shape, and position of these openings for each compartment should be varied according to the required ventilation rate to keep the air velocity within a comfortable range for the pigs within all compartments.
- Results of simulations suggested that CO_2 concentrations varied along the trailer and were considerably higher towards the front. This suggests that ventilation rates were lower towards the front than towards

the rear of the trailer. To overcome this problem, the ventilating holes in the side walls of the front compartments should be larger than those in the rear of the trailer. In this manner, the air movement in the front would be more consistent with the air movements in the other compartments.

- For current trailer designs, the number of the sidewall slats open or closed can only be adjusted using slats, however, it is not possible to vary the number of slats open or closed between the top and the bottom decks. Having this capability would allow for separate ventilation of the two decks of the trailer and, therefore, should provide more optimal conditions on the two decks. A guideline for installing the side slats is needed; however, to develop such a guideline will require further model development with more detailed and accurate geometrical modeling of the side openings and the impact of opening or closing these with slats.
- An automatic system for changing sidewall openings based on external conditions would be the ideal and should be explored. Conditions change so drastically and quickly, from loading at the farm to travel on the road, to the period of waiting at the plant, such that it is unreasonable to assume that one set of ventilation openings can handle all situations and still maintain pig comfort.
- The sidewall openings on the trailer design used in this study were inadequate for hot weather, particularly when the truck was stationary. Manufacturers need to explore ways to increase sidewall openings, and these openings need to be combined with an automatic system to change the size of the openings. Results of the simulations indicate that the ventilation openings should probably be managed as three independent systems, namely, the front two compartments on both decks (compartments 1 and 2), the center two compartments on both decks (3 and 4), and the rear compartments on both decks (5 and 6).
- It is recommended that fans be installed in the front end-wall to blow air backward along the trailer. Installation of one large A/C fan in the front end-wall of the trailer on each deck will provide some airflow in summer. The fans could be covered and/or removed for winter. Mounting the fans in the end-wall would reduce the interference with the loading and unloading processes, and would keep the fans out of the reach of the pigs.
- Dry bedding is important in cold weather, and wetted bedding could be useful in summer for improving heat transfer via evaporation. The physical properties, especially the heat transfer characteristics, of the bedding material need to be established for this to be included in the simulation model to identify the most appropriate type and amount of material to use with different environmental conditions.
- There are a number of areas that warrant further study to provide a better understanding of the micro-environment experienced by the pigs during transport. These include:
  - Taking measurements at several locations in each compartment.
  - Use of video cameras in conjunction with sensors to monitor the activity levels of the pigs and help determine the link between pig behavior and aspects such as heat and carbon dioxide production.
  - Use of more advanced air velocity sensors to determine the direction as well as the velocity of air movement within each compartment.
  - Use of different pig stocking densities on the trailer to determine the influence of the number and weight of pigs on environmental conditions.
  - Use of tracer gases to accurately determine ventilation rates for the entire trailer and for individual compartment.

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