Environmental conditions in typical cattle transport vehicles in Scandinavia

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Abstract

The current licentiate thesis is dealing with transport of cattle from farms to abattoirs. During transport the animals are confined in the vehicle and are exposed to an unfamiliar environment, including heat, cold, humidity and vibration that might be stressful to them. To determine how inside condition in the vehicle during transportation varies depending of season, loading density, transport time and dynamic performances field experiments were made in commercial cattle transport vehicles. The vehicles used had natural ventilation system with air suspension in the front axis and leaf suspension system in the rear axis. Air quality in the compartment in terms of temperature, relative humidity and gases (ammonia, methane and carbon dioxide) were mapped out in Sweden. In Sweden and in Norway was vibration in three axes on the vehicle investigated, and in Norway also velocity and slope as well as the animal's behaviour. An animal transport surveillance system that considers environmental parameter in the vehicle as well as the physiological response parameters has been developed to store and transfer data to a control station.

Average inside temperature was 3 °C to 6 °C warmer than outside temperature and high animal density made the average temperature higher irrespective of outside temperature. Stops that were made to load new animals lowered temperature during winter but made it higher during summer. Experiments found no detectable methane levels and the maximum ammonia level increased with transport time. There was a significant difference between the performances of the vehicle when loaded and unloaded. Animals preferred to stand perpendicular to the direction of vehicle's motion during transport and they lost their balance more often on a curvy road than on a straight road. The surveillance system was found to perform well and will promote animal welfare. To improve the animals welfare during transport further detailed studies about environmental conditions is recommended.

Keywords: Transport, cattle, air quality, temperature, gas, vibration, road condition, behaviour, welfare

Contents

Appendix

Papers I to III

This thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Wikner I., Gebresenbet G & Nilsson C. 2003. Assessment of Air Quality in a Commercial Cattle Transport Vehicle in Swedish Summer and Winter Conditions, *German veterinary journal,* **110**, 100-104.

II. Wikner I., Gebresenbet G & Tolo E. 2003. Dynamic Performances of Cattle Transporting Vehicle on Scandinavian Roads and Behavioural Response of Animals. *German veterinary journal,* **110**, 114-120.

III. Gebresenbet G., Wikner, I., Van de Water G., Freson L & Geers R. A smart system for surveillance of animal welfare during transport. Conference paper for World Buiatrics and accepted for publication in the *German veterinary journal.*

The papers are published with permission of the journals concerned.

1. Introduction

1.1. Background

Animals are often transported a long way from farms to abattoirs and the distance between farms and the abattoirs steadily increases because of rationalisation of abattoirs. Transport of animals includes loading, driving time and unloading. Between the loading and unloading events the animals are confined in a moving vehicle where they are exposed to an unfamiliar environment that might be very stressful and lead to poor welfare. Figure 1 shows how the animal's welfare during transport is affected by vibration in the vehicle and by eventually poor air quality in the compartment. There are many factors that may increase or decrease the degree of the stress the animals are subjected to in terms of vibration and bad air quality.

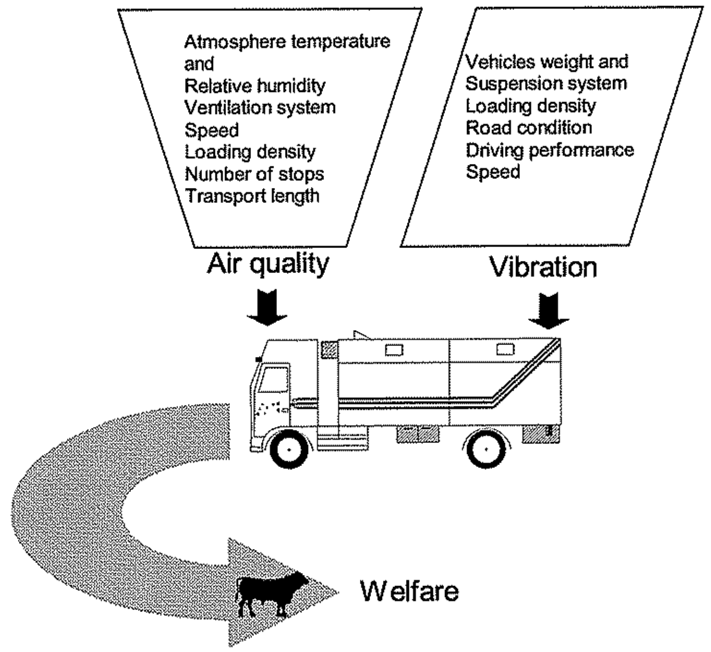


Figure 1. Animal welfare during transportation is affected by inside air quality and the vibration of the vehicle.

The quality of the air inside a transporting vehicle depends on the vehicles ventilation rate (can be forced or natural), place in the compartment, number of animals on the vehicle, their heat production, outside air temperature and relative humidity. It has been found that inside temperature depends mostly of ventilation size and not of the vehicles weight, size and construction (Randall & Patel, 1994). Natural ventilation is variable and depends on vehicle movement, wind speed and direction. It is difficult to control compartment climate with natural ventilation, the only way is to open and close the ventilation apertures. The ventilation may be inadequate both in winter and in summer condition. In winter the ventilation must be limited otherwise it will be too cold in the compartment and this might lead to high levels of relative humidity, carbon dioxide and ammonia. In summer the temperature can increase to hazardous levels when the vehicle is stationary. High inside temperatures can cause heat stress and eventually lead to animal's death. To ensure the welfare of cattle during transport recommendation limits of temperature and relative humidity as well as levels of harmful gases based upon fundamental characteristics must be available. How the temperature varies inside the compartment is also important to have knowledge about since it is difficult to get even ventilation throughout the compartment with natural ventilation systems.

Vibration in the moving vehicle is one of the factors considered to be an acute stressor causing physiological and behavioural-stress on animals (Stephens and Rader, 1983), and it may have influence on health, comfort, and activities and cause motion sickness (BSI, 1987). The vibration that the animals are subjected to is depending on type of vehicle (suspension system, weight, length), road type (surface and undulation), animal's position in the vehicle and the driving style of the driver. Several researchers have studied the levels of vibration of pigs and poultry transporters as well as the effect of vibration for the animals during both experimental and commercial conditions. However, the vehicles that are transporting animals are often specific for the species transported. Dynamic performances for different conditions for cattle transporters are therefore necessary to investigate so data will be available also for cattle.

1.2. Literature review

A survey on earlier investigations dealing with air quality inside animal transport vehicles and the animal's response to it is followed by a survey of investigations concerning dynamic performances of animal transporting vehicles and its effect on animals.

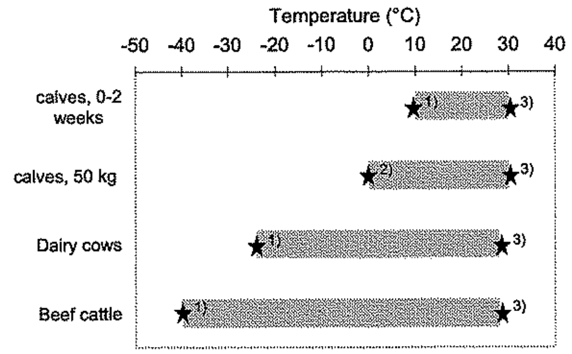
1.2.1.Air quality

Temperature and relative humidity

Compartment temperature is the most important air quality parameter. Heat stress in animals can lead to changes in body temperature and to a higher mortality rate during transport. Animals can also be exposed to dehydration that can lead to meat of less quality. Cattle maintain their body temperature by producing or loosing heat by sweating or panting (Mount, 1974). Cattle are homeothermic animals so they can maintain a constant body temperature within a thermoneutral zone (TNZ) limited by lower and upper critical temperature limits (LCT and UPT). Heat as well as cold stress may occur at temperatures outside the TNZ. TNZ depends on activity, age, species, breed, previous state of temperature, pen condition, feed level, water intake, animal density and the animals fat and coat because these things are affecting the animals ability to loose heat. Sudden transfer of transporters to environments that differ greatly from the environments that the animals are used to can cause acute heat or cold stress (Webster, 1981). Before entering this kinds of transports the animals need to be acclimatized. A wet coat higher LCT and air velocity makes both the LCT as well as the UCT higher because it enhances heat loss. In hot condition this might be a positive thing but if

the temperature is low it can influence the animals negatively. An increase in air velocity from 0.22 to 4.44 m/s at a temperature of –7 °C will increase the heat loss with 25% from dairy cows (Esmay & Dixon, 1986).

TNZ is smaller for calves than for adult cattle and lactating cows have a larger zone than unlactating cows. Also beef cattle with a high growth rate have a large TNZ. LCT and UCT varies in the literature and ranges from +10 °C and +30 °C for 0 to 2 weeks old calves (Lindley & Whitaker, 1996; Wathes *et al.*, 1983) to –40 °C to +28 °C for beef cattle with a high growth rate (Lindley & Whitaker, 1996). Figure 2 shows clearly the large difference in LCT and small difference in UCT for cattle at different production levels.



Lower critical and upper critical temperatures, (★), are taken from the following literature:
1) Lindley & Whitaker, 1996
2) Webster, 1981,
3) Wathes *et al.*, 1983

Figure 2. Thermoneutral zone (TNZ) limited by lower critical temperature (LCT) and upper critical temperature (UCT) for cattle at different age and production levels.

High relative humidity is of great importance when temperature is high because it prevents the animal's ability to loose heat by evaporation. High relative humidity together with low temperature may lead to enhanced heat dissipation for the animals followed by cold suffering. In livestock houses Esmay and Dixon (1986) recommended 80% as the highest level of relative humidity and CIGR (1984) suggested that it should be kept under 80% if the temperature is higher that 10 °C and 60% with temperature as high as 30 °C. Recommended limits of temperature for cattle transport vehicles have been settled in a report from EU (EU/HCPDG, 1999), taken into consideration relative humidity, see Figure 3.

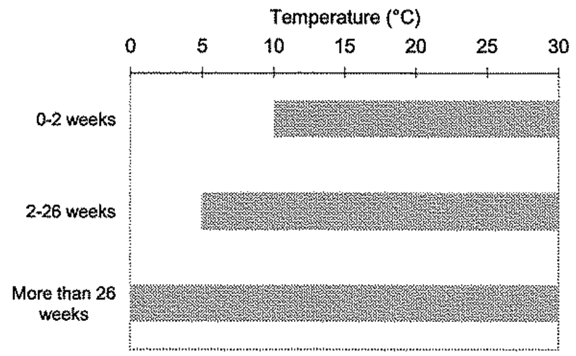


Figure 3. Recommended temperature limits for cattle of different age in transporting vehicles. If relative humidity exceeds 80% the recommended maximum temperature will decrease with 3 °C (after EU, HCPDG, 1999).

General requirement about the ventilation says that ventilation must ensure the animals welfare during transport. If the transportation exceeds eight hour regulations in EU, (council regulation (EC) No 411/98), says that the vehicle must be equipped with a ventilation system that can be used at any time whether the vehicle is moving or not and that the system should be either a forced ventilation system or a system that ensure a temperature range of 5 to 30 °C with a ± 5 °C tolerance depending of outside temperature.

When measurements of temperature and relative humidity were made by Christensen & Gade (1996) in a pig transporting vehicle in winter and autumn it was found that the temperature above the pigs were lower (1 to 6 °C depending on outside temperature) than the temperature between them. Temperature as well as relative humidity didn't differ much between pens in these experiments. Relative humidity was highest at the start of the measurement and ranged from 90 to 95% with an outside relative humidity of 80 to 92% during the experiments made in autumn. During winter the relative humidity was 75.6 to 98% inside and 89 to 98% outside the vehicle. Christensen & Gade (1986) also found that when the vehicle made a stop of 5 minutes the temperature increased with 5-8 °C.

Holleben (2003) found the average inside temperature to be 3 °C higher inside a cattle-transporting vehicle than outside the vehicle. Inside temperature ranged from 0.3 to 22 °C while the outside temperature ranged from –4 to 19 °C. Average relative humidity were slightly higher inside the vehicle than outside, it ranged from 57.3 to 100% inside the vehicle and 59 to 99% in the air outside. During a transport of cattle for 5, 10 and 15 hours and a density of 1 m²/animal, no differences in temperature were found between pens in the vehicle or between inside and outside temperature (Warriss *et al.*, 1995).

Gases

Carbon dioxide can be irritating to the respiratory organs and at very high concentrations cause asphyxiation (Wathes *et al*, 1983). Carbon dioxide is exhaled by the animals and can therefore be used as an indicator of ventilation intensity. Highest level of carbon dioxide that animals should be exposed to is set to 3000

ppm both in animals housing (CIGR, 1992) and in animal transporters (Randall, 1993; EU/HCPDG, 1999). Ammonia is a gas that can be irritating to eyes and mucous membrane. It is produced from the animal's faeces and the maximum level is set to 20 ppm in livestock houses (CIGR, 1992).

1.2.2. Vibration

The motion caused by the moving vehicle is the cause of vibration that the animals are exposed to. Vibration can be described by its direction, acceleration magnitude and frequency spectrum (Randall, 1992) and can be expressed as root mean square value (RMS) that is the frequency-weighted acceleration of the acceleration signal and as power spectral density (PSD). Human response of vibration is well known, some attempts have been made to apply this on poultry and pigs but differences in morphology and body mass makes it impossible to use optimum levels for human on animals (Randall, 1992; Randall & Mehan, 1993; Stephens & Perry, 1990). Most studies made on vibration have been dealing with poultry and pigs and the transport vehicle that is carrying these animals, just a few have been concentrated on cattle.

Levels of vibration in animal transport vehicles

Different studies regarding vibration measurements have been made to find the frequencies and acceleration magnitudes on commercial poultry and pig transport vehicles, one study made experiments on a cattle transport vehicle. The vertical axis was the dominant one on pig and poultry transporters (Randall & Mehan, 1993; Behrends *et al*, 1997). Randall *et al.* (1997) found that broiler chickens had more against vertical motion than to motions in the horizontal directions.

Studies have shown that the acceleration magnitude in the vertical axis is low in animal transporters and that these levels would be very aversive to humans (BSI, 1987). In one study the magnitude of vibration acceleration had levels of 0.07 to 1.75 m/s² (Behrends *et al.*, 1997), in two other studies the levels were lower, it ranged from 0.05 to 0.53 m/s² in poultry as well as in a pig-transporting vehicle (Randall *et al.*, 1995; Randall & Bradshaw, 1998). In these studies the magnitude was much lower when the vehicle was loaded. In one study it was found that the differences in acceleration magnitude between loaded and unloaded was larger for vehicles with leaf suspension system than with air suspension (Randall *et al.*, 1995).

Several studies have found that the typical vibration frequencies in animal transporting vehicles are 1 to 4 Hz with a second peak at 10 to 12 Hz in the vertical axis. For example have Randall *et al.* (1993) studied the frequencies in poultry transporters, and they found that the main frequency in the vertical axis was between 1 and 2 Hz with a secondary peak at 10 Hz, also when the vehicle was unloaded the main frequency was 1 and 2 Hz. In the lateral axes 1, 2 and 11 and 12 Hz was the main frequency when the vehicle was loaded, when it was unloaded the higher frequencies was more dominant. In the horizontal axes, 1 to 2 Hz, were the main frequencies both with the vehicle loaded and unloaded. In another study Behrends *et al.* (1997) found almost the same main frequencies but only in the vertical direction. Vertically it was 3, 4 and 11 Hz with the vehicle loaded and unloaded, with half the acceleration magnitude when loaded. Lateral axis gave vibration frequencies of 1 and 17 Hz when loaded and 14 Hz when unloaded. In horizontal axis the main frequencies was around 18 Hz loaded and 9.5 Hz unloaded. Randall & Mehan (1993) studied vibration on a pig transporter and they found similar values of fundamental frequencies. It was 2 Hz loaded and 3 Hz unloaded in the vertical axis and 18 Hz in lateral axis with loaded vehicle. Vibration in the horizontal axis was always negligible.

The vehicles are different in terms of weight, length and interior so it is not possible to transpose the results made on poultry and pigs transport vehicles on vehicles that are transporting cattle. Only one study has studied vibration frequencies in cattle transporters. Gebresenbet & Eriksson (1998) found the dominant frequencies to be 2, 4, 8 and 12 Hz in the vertical axis in a commercial cattle transport vehicle.

Increased speed made the vehicles vibration higher in one study (Randall & Mehan, 1993) but in another study (Randall *et al.*, 1995) it was found that an increase in speed not always increased vibration, the vibration was also depending on type of vehicle (weight and suspension system) and road type. Both these studies found that poorer road quality during the same speed gave more vibration on pig transport vehicles.

Effect of vibration on animals

Studies have been made to find which levels of vibration that animal find aversive and most of them have been dealing with poultry. Many studies in experimental conditions have shown that low frequency levels of vibration are the most aversive to poultry even though the number of frequencies and the frequency levels tested have been different in these studies. Also acceleration magnitude has been different.

Rutter & Randall (1993) tested vibration with low frequencies and found poultry to have more aversion to vibration at 1.0 Hz (1.5 m/s²) than to 0.5 Hz (0.6 m/s²). In another study Duggan *et al.* (1995) tested higher frequencies, but found also that poultry elicited fear at low frequencies of 1.0 (1 m/s²) and to 2 Hz (2 m/s²). Carlisle (1998) found the opposite than the above researchers. Higher frequencies, 5 and 10 Hz (2 m/s²), induced more physiological stress on poultry than lower frequencies. This experiment was carried out during road transportation so it might be difficult to compare it with the studies mentioned earlier that were performed under experimental conditions. Randall *et al.* (1997) tested vibration between 0.5 and 10 Hz in the vertical direction with acceleration magnitudes between 0 and 5 m/s². The broiler chicken found the frequencies of 1 and 10 Hz with an acceleration magnitude of 1.05 and 3.46 m/s² respectively to be "very aversive". "Little aversive" was 1 Hz (0.28 m/s²) and 10 Hz (0.92 m/s²).

Perremans *et al.* (1998) studied the effect of vibration on heart rate in pigs, and they showed up the greatest sensitivity to vibration at 8 and 18 Hz in combination with 3 m/s². Frequencies of 2, 8 and 18 Hz were tested in combination with 1 and 3 m/s². In a later study Perremans *et al.* (2001) found that pigs are most susceptible

in terms of cortisol, adrenocorticotropic hormone levels and behaviour to low frequencies of 2 Hz and 3 m/s², in this study 2, 4, 8 and 18 Hz were tested in combination with 1 and 3 m/s². They also found a susceptibility to high frequencies (18 Hz, 3 m/s²) after a while of vibration exposure.

To find out how the cattle are influenced by vibration, data made on cattle must be available due to the difference in body mass for the different species. In one study young calves were tested in a vibration machine at vibration frequencies of 2, 4, 8 and 12 Hz in combination of 1 and 3 m/s². They had an increase in cortisol level as well as the largest number of movements at vibration of 2 Hz and 3 m/s² (Van de Water *et al.* 2003). Van de Water *et al.* also found that heart rate were highest at this vibration frequency, but only during the firs hour of exposure, during the second hour heart rate decreased. The frequency of 2 Hz and 1 m/s² didn't influence the animals at all.

Behaviour

Behavioural and physiological changes are responses to stressor (Gross & Siegel, 1993) and the driving performance affect the vibration and the behaviour of the animals. Horizontal vibration is influenced by the animal's orientation and posture changes may occur for poultry to compensate for the vehicles swaying that can depend on the road undulation and curvature (Scott, 1994). Randall (1992) found that rapid breaking or acceleration affected the postural stability of the animals since it was the cause of vibration in the horizontal axis.

During transport cattle prefer to stand either parallel or perpendicular to the way of motion (Kenny and Tarrant, 1987 a, b; Tarrant *et al.*,1988, 1992; Nanni Costa *et al.*, 2003). Perpendicular to the way of motion was the most common orientation during long transports and the orientation least used was the diagonal one (Tarrant *et al.*, 1992).

It happens that cattle loose their balance and are going down during transport, this increase carcass bruisings and cause suffocation to the animals. Tarrant *et al*, (1988) found that steers lost their balance more during high density than during low density and that the problem to keep the balance was caused by driving events like cornering, gear changes and braking. They also found that Steers transported at high stocking density had less movement (16 for high and 109 for low density) and that threats and butts increased with decreasing density.

2. Objectives

The objective of this work was to find details in how the air quality inside a commercial cattle transporting vehicle varies in summer and wintertime under different conditions such as transport length, loading density and stops to load new animals. The intention was also to find the vibration levels of a commercial cattle-transporting vehicle on typical roads in Norway and to see how it affects the animal's behavioural alteration. Another intention was to develop a surveillance system for cattle transporters so the animal's condition inside the vehicle could be supervised.

3. Materials and Methods

The experiments used for these papers have been made during ordinary commercial journeys with slaughter cattle that have been transported from farms to the abattoir. The journeys were selected by the driver to match animal category, transport time and loading density.

3.1. Vehicles and animals

Both Swedish (Paper I and III) and Norwegian (Paper II) experiments were carried out with the same type of vehicle, a Volvo FM 12 with air suspension system in the front axis and leaf suspension system in the rear axis. The vehicles used in Sweden had four fixed pens and could carry 16 adult cattle as a maximum while the Norwegian vehicle could carry 12 adult cattle in four pens of varied size. Swedish experiments were made with at the least five young calves to the maximum load and all Norwegian experiments were made with full load. The room for each animal were in both vehicles 1.5 m². The Swedish vehicle had a natural ventilation system with eight openings that could be adjusted from being closed to open. In Figure 4 a bull has been loaded on to the vehicle used in Swedish experiments. The ventilation openings on the right side of the vehicle are opened while the front openings are closed. Instrumentation package in the left upper corner is also visible as well as the girth belt with the heart rate monitor in a plastic box.

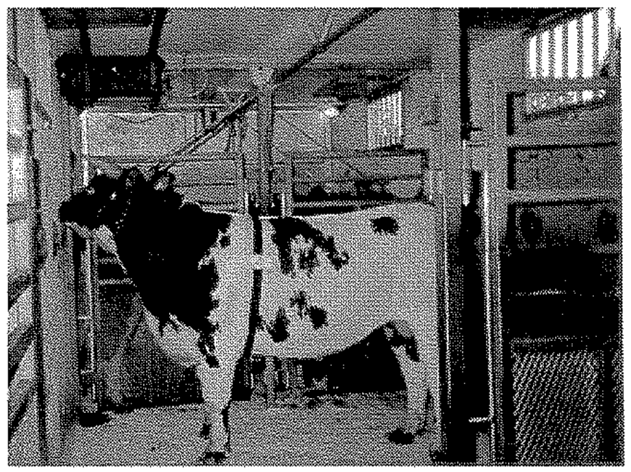


Figure 4. A bull on the vehicle used for the experiments in Sweden.

3.2. Parameters and sensors

The important parameters considered in the experiments were air quality, vibration level and behaviour. The parameters were measured during different transport times, loading densities, seasons, and velocities of the vehicle and on roads of different quality. The vibration in the vehicle and their effect of the cattle were quantified by the animal's behaviour. The temperature outside the vehicle and compartment temperature, relative humidity, ammonia, methane, carbon dioxide, and oxygen were also quantified.
The instruments used were:

- TESTO- temperature and relative humidity
- Toxi Ultra - ammonia
- GA 2000 - methane carbon dioxide, and oxygen
- Cargolog - vibration
- Video camera, Sony Hi-8 - behaviour

4. Air quality inside a commercial cattle transport vehicle in Sweden (Paper I)

The objective of this paper was to find levels of temperature, relative humidity and harmful gases in the compartment during summer and winter conditions and to find the effect of stocking densities, transport time and stops of the quality of the air. The evenness of the compartment temperature was also studied.

The vehicle used was as mentioned earlier a VOLVO FH 12. The vehicle had a natural ventilation system with ventilation openings that could be manually adjusted from being closed to open. During the experiment five to 16 calves or adult cattle (load weight ranging from 1. 3 to 10 ton) were on the vehicle.

Air temperature was measured with one sensor outside the vehicle and four sensors at different places inside the compartment. Ammonia, methane, carbon dioxide and oxygen were measured at on place. To perform the experiments young calves, cows and young bulls were transported for different long time (<2 h, 3-6 h, 8-12 h) and with different loading densities. The number of stops that occurred to load animals during the journey was noted.

A simplified model of how the temperature inside the compartment is balanced by the animals heat production and ventilation is illustrated in figure 4.

Notation

A compartment envelop area, m^2
C specific heat of air, Wh m^{-2} K^{-1}
I solar radiation, W m^{-2}
P_{prod} heat production inside compartment, W
Q ventilation air flow, m^3 h^{-1}
T temperature, K or °C
U heat transfer coefficient, W m^{-2} K^{-1}

Subscripts

i inside
o outside
p constant pressure

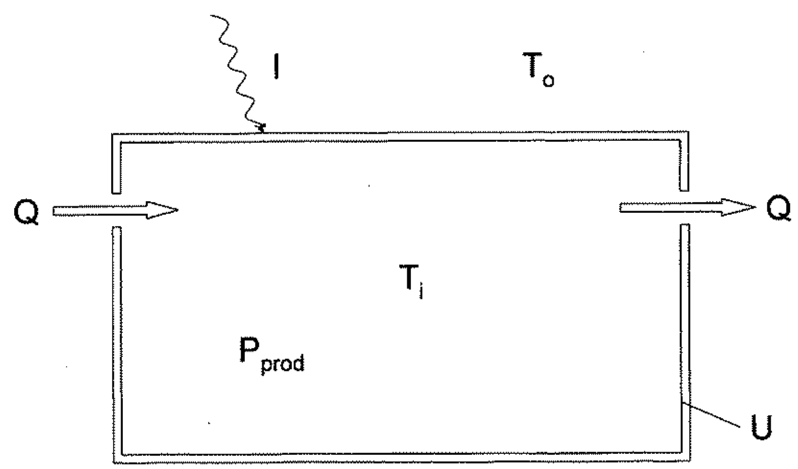


Figure 4. A simplified model of compartment heat balance.

The heat production inside the compartment (P_{prod}) arises from the animals and is determined by *e.g.* number of animals (stocking density), animal weight and activity. In our case it may be reasonable to disregard solar radiation (I) as most of the transports were carried out during night time and early mornings. If solar radiation is neglected the heat balance can be expressed as:

$P_{prod} = A\,U \times T + Q\,C_p \times T$ where temperature increment is $\times T = T_i - T_o$

The equation above may be rewritten as:

$\times T = P_{prod} / (A\,U + Q\,C_p)$

which expresses the theoretical temperature increment inside the compartment.

Average inside temperature was always higher than outside temperature. In average the mean temperature inside the compartment was about 3 °C and 6 °C higher than outside temperature. Temperature inside the vehicle was during some winter journeys very low, at the beginning of one journey it was –16 °C and it took two hours of driving to reached 0 °C. The difference between inside and outside temperature decreased with transport time. The differences in average inside temperature between pens within the same journey varied from 0.4 to 3.1 °C in summer and from 0 to 7.7 °C in winter. Pen 1 (nearest cabin) had lowest temperature in winter and the difference between Pen 1 and Pen 3 (nearest opening gate) were much greater when many stops were made to load new animals (Figure 5).

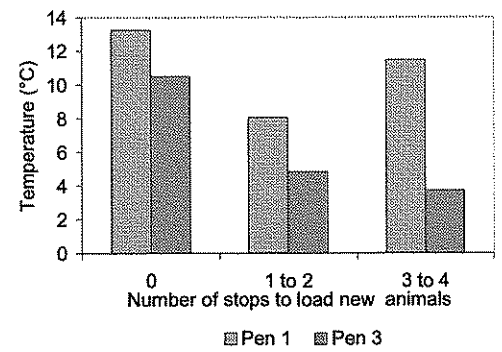


Figure 5. Average temperature increment between the front pen (Pen 1) and the pen nearest opening gate (Pen 2) when different numbers of stops to load new animals were made during winter experiments.

Many stops to load new animals lowered the average temperature increment and relative humidity in winter time, this might depend on the fact that outside temperature during winter was much lower than the inside temperature and outside air came into the vehicle when the ramp was opened. In summer more stops increased compartment temperature and relative humidity, this might be explained by the fact that a stop also results in decreasing air circulation through the ventilation openings that lowers ventilation heat losses.

Average relative humidity for all summer journeys were 89.2% and for all winter journeys 90.9%. Relative humidity decreased when transport time increased during both summer and winter. More stops lowered relative humidity during winter but made it higher during summer time. Higher stocking density resulted in higher relative humidity during both seasons.

Average ammonia level varied between 3 and 6 ppm depending on stocking density and number of stops with a maximum value of 18 ppm. No detectable methane levels could be found inside the compartment at any time.

5. Performances of a cattle transport vehicle (Paper II)

The main objective of this paper was to investigate the vibration levels of an animal transport vehicle on typical roads in Norway. The intention was also to study the effect of driving performances and road conditions on animal welfare in relation to behavioural alteration.

Experiments were made in the Ålesund region on the west coast archipelago in Norway in November 2001. The vehicle that was used for the field experiment was as mentioned earlier a VOLVO FH12 that has a metal floor with no covering except bedding with saw dust. During the experiments tri-axial vibrations on the vehicle was measured, as well as speed, altitude and position (latitude and longitude). The animals were video recorded for behavioural analyses.

Three road types were identified, straight and plain (road A), curvy (road B) and one gravelled road (road C). Measurements on both road A and C was made with the vehicle loaded and unloaded. Events such as sudden stops and curves were observed and noted. Ferry travelling and roads that lie as high as 527 meter above sea level were included in the experiments.

For vibration measurements a tri-axial accelerometer unit was mounted under the floor of the loading compartment. Vibration was recorded in three mutually perpendicular directions to the direction of motion (x, y and z-axis). X-axis was vibration in the horizontal direction, z-axis was vertical and y-axis was the lateral direction. The smallest value that could be stored continuously was $\pm$ 0.98 m/s^2. Caused by this limitation of the instrument, sampling equal number of data per unit time was not possible. As a consequence, no frequency analysis has been performed using the sampled data. Comparisons were made using the vibration amplitude and distribution of the sampled data per unit time for the three road types that were used for the experiment.

Alteration of the behaviour were analysed and focus was on different behaviours such as; moving one or several foot, loosing balance, touching wall besides or behind the animal, changing position, orientation, and if the animals were fighting or were alert.

There was a significant difference between the performances of the vehicle when loaded and unloaded. Very high vibration values were noted during the empty driving. On the best road, road A, most values were measured in z-axis when the vehicle was loaded. When the vehicle was unloaded, there was almost equal number of values measured for all directions. Average vibration amplitude was higher without animal than with animals for x, and y-direction but lower for z-direction. The biggest difference of most common value with and without animal was seen for z-axis where the focus changed from -1.0 to 12.8 m/s^2. When the vehicle was empty there were no small values between -7.8 to 7.8 m/s^2 in z-axis, and with animals the vibration was damped and had focus around zero, this is illustrated in Figure 6.

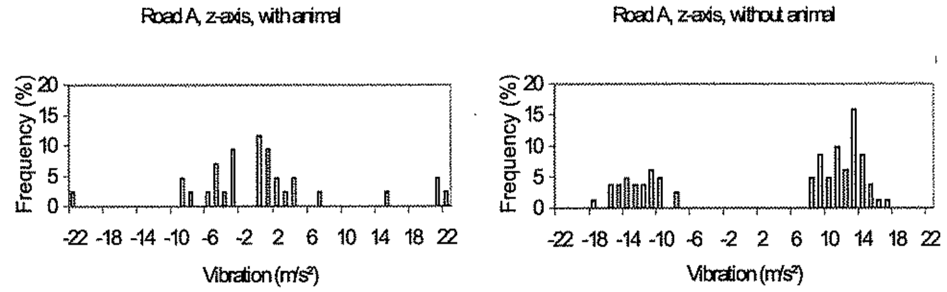


Figure 6. Distribution of vibration values for z –axis during transport on road A that was a road of good quality. Vibration values are illustrated both with and without animals on the vehicle.

Road C was a small and gravelled road and recorded most measured vibration values of the three road types especially with the vehicle loaded. The main difference of vibration distribution between loaded and unloaded was seen in z-axis where the focus changed with 25.5 m/s^2 and the average vibration value increased almost nine times.

Vehicle speed depends of the roads speed limit and the slope variation of the road. The speed was highest on the best road that also had the lowest altitude change, the lowest speed had the gravelled road with a high altitude change. On ferry transport animals were calmer and less and smaller vibration amplitudes were observed than on road transport. The animals reacted differently when driving on roads of different types. When driving on the good road they were more relaxed but bumped quite often in to the walls or had to take steps to maintain their balance. This happened mostly when the vehicle took a turn or had to brake and is mainly depending on driving performance. It has also been noted that animals prefer to stand perpendicular to the direction of vehicle's motion during transport.

A similar experiment as performed in Norway has been made in Sweden. The experiments in Sweden were made with a similar vehicle and the same equipment mounted on a pole in the loading compartment. There were differences between the vibration distributions between the two countries. The number of measured vibration values was much larger during Swedish than Norwegian experiments. One explanation could be that the measurement unit was mounted in different places during the two experiments.

6. Smart surveillance system (Paper III)

The objective of this paper was to develop a transport surveillance system for cattle transport vehicles. The aim was that this system would be able to integrate individual identification of animals, place and time of loading and unloading and also compartment air quality as well as vibration and behaviour of the animals.

The work for this paper has been performed both in Belgium and in Sweden. Only the part performed in Sweden is mentioned here. The parameters considered for this investigation were: heart rate, animal behaviour, temperature in the vehicle, vibration, locations of farms in relation to the abattoir, routes of transport, distance, time, transport speeds, road conditions, and air-emission from the truck. The instrumentation used may be divided into groups depending of what they measure:

1. Animal behaviour and heart rate
2. Transport route and geographical location
3. Vibrations
4. Climatic conditions (temperature, humidity, ammonia, methane, carbon dioxide and oxygen)

Parameters were monitored using on-board portable computers.

The vehicle used for the study was as described earlier Volvo FH12. The heart rate of the animals was measured continuously throughout the handling and transport time. A video camera was mounted in the front pen that recorded the alteration of animal behaviour. A tri-axial accelerometer was mounted on rear axle on the floor of the second pen where the test animals were placed and measurements of vibration were taken for different speeds of the vehicle on different road types. Measurement of climatic conditions was monitored using the same instrument and sensors as described in Paper I. MODTRANS, a model describing the material flow and air emission (Gebresenbet & Oostra, 1997), was used to determine the transport work for each route and air emissions such as carbon dioxide, carbon monoxide, hydrocarbons and oxides of nitrogen. A GPS measured position (longitude and latitude), slope, time, velocity, and satellite signal quality. To measure the transport routes, the Global Positioning System (GPS) and the database for digitized maps and optimising software (DPS) were used. For the measurement of the route and location of the farms, DGPS signal receiver was used. Using the receiver the following parameters were determined: locations of the producers, locations of delivery points, routes of distributions, altitude from sea level, and speeds of vehicles.

A wireless data transmission system has been developed that is able to promote animal welfare by introducing direct an on-line control system. The comprehensive field measurement that was made to evaluate the system found that the package performs well. For the work of the optimisation and route planning 21 routes were made. Transport distance was reduced by 8% to 22% and the emissions from the vehicle reduced by 15% to 25%. Optimisation of one transport route decreased transport distance by about 10%. Emissions of ammonia, methane and carbon dioxide were under the limited range of standards given by CIGR (1992) for animal housing conditions.

7. General discussion and conclusions

7.1. Discussion

The Environmental condition in vehicles is far from optimal. It was found that average temperature inside the vehicle during some journeys in winter was lower than the recommended value of 0 °C for adult cattle (EU, HCPDG, 1999). Compartment average temperature was always higher than outside temperature that is according to theory. Temperature differences between the pens varied within the same journey from 0 to 7.7 °C, and the differences were larger during winter than during summer. It was warmer in the front pen than in the pen nearest opening gate during winter and the difference increased with number of stops. More stops to load new animals affected also the average temperature and relative humidity during wintertime, both temperature and relative humidity decreased. This might depend on the fact that outside temperature during winter was much lower than the inside temperature and outside air came into the vehicle when the ramp was opened. The maximum ammonia level increased with transport time. At the end of a transport the ammonia level could be as high as 18 ppm, which is close to the highest recommended value of 20 ppm in livestock houses (CIGR, 1992). The average level of ammonia was 3 to 6 ppm.

There was a significant difference between the performance of the vehicle when loaded and unloaded. The vibration was reduced almost by 10 times when loaded during transport on gravelled roads. Other researcher has suggested limitation of driving animals in vehicles that only is partly loaded when they have concluded the same result (Randall & Mehan, 1993). Due to the instrument limitation no frequency analysis were made and therefore it is hard do compare the levels measured here to others researchers work. The animals lost their balance more when driving on the curvy road but the straight road caused most events where the animals touched the wall beside them. It seemed like the animals were more alert on the curvy road and were prepared for the vehicles swaying. Animals preferred to stand perpendicular to the direction of vehicle's motion. The same preference together with the parallel direction has been found in earlier investigations (Kenny and Tarrant, 1987 a, b; Tarrant *et al.*, 1988, 1992; Nanni Costa *et al.*, 2003). Gravelled road caused higher vibration in the vertical direction than in the other directions. That the vertical direction is dominant have been pointed out in other studies (Randall & Mehan, 1993; Behrends *et al.*, 1997; Randall *et al.*, 1997), it has also been found that broiler chickens has more against vertical motion than to motions in the horizontal directions. This road type caused also more vibration than the other road types when unloaded, even if the speed was lower. Randall and Mehan, (1993) and Randall *et al.*, (1995) found that poorer road quality gave more vibration during the same speed on pig transport vehicles. Less and smaller vibration amplitudes were observed on the ferry than on road transport and the animals were calmer. This suggests that the animal relax with a decrease in vibration amplitude and that vibration force the animal to be alert for keeping balance during driving.

The surveillance system developed could trace all animals from farm to abattoir while measuring transport performance and animal conditions could monitor animal welfare. Application of route planning could be recommended to reduce the transport distance and time, thereby reducing stress on animals and emissions generated from the vehicles. More over, using route planning unfavorable roads, such as jammed roads or roads causing a lot of vibration could be avoided and this would improve animal's welfare.

7.2. Conclusions

- Inside temperature follows the outside temperature well with the ventilation apertures fully opened
- Temperature variation between pens were larger with lower outside temperature and is affected of stops to load new animals
- At very low outside temperatures the number of stops when the ramp is opened should be kept to a minimum in order to avoid too low temperatures in the compartment
- Animal reduce the vibration especially on gravelled roads and therefore should partly loaded vehicles be avoided on these roads
- Animals lost their balance more when driving on a curvy road than driving on a straight road
- Animals prefer to stand perpendicular to the way of motion
- It is possible to overview compartment environment with the surveillance system and this information could lead to improved animal welfare
- It is important and essential for the animal's well being to be able to maintain an optimal condition in animal transporting vehicles and to fulfil this further investigation in this area is recommended.

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