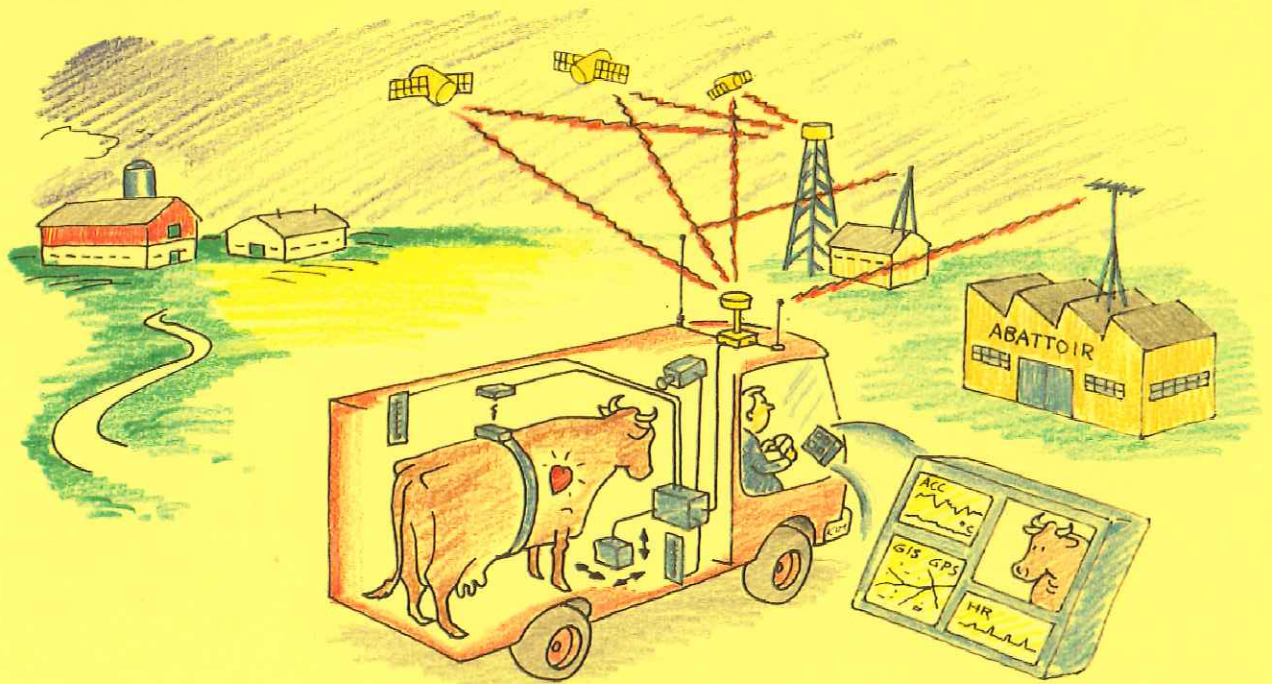


Effects of transport and handling on animal welfare, meat quality and environment with special emphasis on tied cows

Girma Gebresenbet and Björn Eriksson



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Girma Gebresenbet¹ and Björn Eriksson²

¹Department of Agricultural Engineering,
Swedish University of Agricultural Sciences, SLU,
P.O.Box 7033, 750 07 Uppsala, Sweden

²Scan Farmek,
P.O.Box 257,
751 05 Uppsala, Sweden

Uppsala 1998

Project co-ordinator

Girma Gebresenbet

Project group

Thore Grahn

Scan Farmek Slakt AB

Björn Eriksson

Scan Farmek Slakt AB

Runar Gustavsson

Scan Farmek Slakt AB

Britt-Marie Möller

Meat Research Institute

Jörgen Ingstedt

Ingstedt Transport AB

Girma Gebresenbet

SLU

Sven Andersson

SLU

Consulted Scientist

Gunnar Malmfors, SLU

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Sammanfattning

Transporter av slaktdjur har ökat de senaste åren i Sverige. Detta är en följd av att många slakterier har lagts ned i samband med rationaliseringar och omstruktureringar vilket medför att slaktdjurena måste transporteras en betydligt längre sträcka än tidigare. Därför är det viktigt att transporter utformas så att djurens välfärd påverkas positivt och att stress kan undvikas i mesta möjliga mån.

Den ökade transporten av slaktdjur kan även medför en ökad påverkan på miljön genom förhöjda emissioner från transportfordon. Hittills har lite eller inget arbete gjorts för att optimera transporter. Ett stort arbete har lagts ned på att kartlägga köttkvaliteten i samband med transporter och handhavande, dock har det ej gjorts någon studie för att helt kartlägga orsakerna till stress genom kontinuerliga mätningar.

Denna rapport redovisar resultat av en studie som är utförd på bundna mjölkkor under transport från gård till Scan Farmeks slakteri i Uppsala. Huvudsyftet med studien var att samla in information som kan användas till att säkerställa transporten av slaktdjur för att förhindra att stressfulla situationer uppstår, samt att utveckla ett effektivt transport och logistiksystem genom att använda informationsteknik för att förbättra transportekonomi, djurens välfärd och miljö. Det specifika syftet var att identifiera huvudorsakerna som kan orsaka stress vid hantering i samband med djurtransporter, samt att simulera och optimera transportroutor och dess påverkan på miljön.

De parametrar som har studerats var hjärtfrekvens, pH, laktat och glykogen koncentration, vibrationer (i tre olika riktningar), temperatur i lastutrymme, bilens hastighet, färdväg och gårdens läge gentemot slakteri genom att använda GPS (Global Position System). Djurens beteende under lastning och transport filmades med en video kamera monterad i lastutrymme.

Resultaten visar att lastningen på gården, körning på dåliga och kurviga vägar, variationer i hastighet, blandning med okända individer från andra gårdar samt avlastning vid slakteri är de händelser som orsakade förhöjd hjärtfrekvenser. Genom videoupptagningen så uppmärksammades en ökad frekvens av gödsling och urinering samt ett visst råmande. En stark rörelse iaktogs i samband med att bilen sattes i rörelse samt vid körning på kurvig och dålig väg.

Mätning av slaktkroppens pH-värde har utförts 45 minuter, 12 timmar respektive 24 timmar efter bedövning. Resultatet påvisade att pH-värdet sjönk ganska snabbt de första 12 timmarna för att sedan sjunka allt långsammare dock med en viss stabilitet. Utvecklingen av pH-kurvan kan beskrivas med hjälp av en exponentiell ekvation. Vid fasställande av slut-pH (efter 24 timmar) så hamnade 20 % på ett pH-värde över 5,8. Koncentrationen av laktat i både muskel och blodplasma mättes. Blodprov togs på varje individ före transport och direkt efter slakt och värdena efter transport ökade med en faktor mellan 1,03 till 4,22.

Insamlade data om vibrationer analyserades för att hitta de högsta resonans frekvenserna. De identifierade frekvenserna är 1.3, 3, 6, 12, 25 och 40 Hz. De första två frekvenserna är typiska för djurtransportlastbilar. Variationen för resonansfrekvenserna var beroende av fordonets hastighet och vilka vägförhållanden som rådde vid mättillfället. Studier visade att den bil som användes i undersökningen har goda prestanda. Ytterligare studier ska genomföras för att säkerställa effekterna av de identifierade frekvenser på både hjärtfrekvenser och pH. Undersökningen visade att en ökning av vibrationsnivån med en faktor 5 ökade hjärtfrekvensen med 80 % och djur som transporterats på sämre och kurviga vägar hade ett högre slut-pH som låg över 5.8, men under 6.2, som är gränsvärdet för DFD under 6.2, dvs ingen DFD. För att helt kunna säkerställa detta faktum krävs mer omfattande studier.

Med hjälp av route-planeringssystemet kan man förkorta transportavståndet med 8-4% . Utsläpp i luften som CO₂, CO, HC och NO_x från bilen var analyserade med hjälp av MODTRANS modell som utvecklades för att studera miljöpåverkan vid livsmedelsdistribution. Resultaten visade att med hjälp av route-planering kan utsläppen minskas med 10 - 18 %.

Denna studie påvisar att fler och mer detaljerade undersökningar av effekterna av transport tid, vibrationernas inverkan på hjärtfrekvens och köttkvalite på fler olika djurslag bör genomföras. Införande av route-planering rekommenderas för att minska transportavstånden mellan gårdar och slakterier .

Summary

Transport of slaughter animals has been intensified in the recent years in Sweden. In connection to rationalization and re-structuring, many abattoirs closed down in the last decades. This implies that the animals should be transported greater distances. During transport from farms to abattoirs, animals may be subjected to un-favourable conditions leading to a compromise of animal welfare and reduced meat quality.

An increase of transport work also contributes to the environmental degradation in terms of air emission emanated from the vehicle. Hitherto little or no attention has been made to optimize the transport work. Important research works have been made to determine the effect of transport and handling on meat quality. However, limited attention has been paid to a comprehensive work to determine the main factors causing stress on animals by making continuous measurement.

The current paper reports the results of study made on transport of tied cows between farms and Scan Farnek's abattoir in Uppsala region. The main purpose of the study was to gather pertinent information which may enable to assess the transport system in detail and to develop an effective transport and logistic system using information technology to promote economy, animal welfare and environment. The specific objectives were to identify main factors which may cause stress on animals during handling and transport, to simulate and optimize transport routes and to determine air emissions from the vehicle to estimate the environmental impact.

The measured parameters were heart rate; pH, lactate concentration, muscle glycogen, vibrations (in tri-axial directions), temperature in the pens, vehicle's speed, transport route and locations of farms in relation to abattoirs using the satellite steered Global Position System (GPS). The alteration of animal behaviour was also recorded using a video camera mounted in the pen.

The results indicated that loading of animals at the farms, transport on rough and curved roads, variation of vehicle's speed, mixing of animals with un-familiar animals from other farms and un-loading at the abattoir are the main events which caused significant increases of heart rate. Urination, defecation, exploration and mooing were the usual behaviour observed during loading and un-loading. The animals lost their balance and rocked during the initial motion of the vehicle and while driving on rough and curved roads.

Samples for pH were taken at 45 minutes, 12 hours and 24 hours after slaughter. The result showed that pH decreased rapidly up to 12 hours and decreased slowly thereafter and maintained steady state before 24 hours. The measured pH values could be described using an exponentially decaying type of equation. About 20% of the animals had the final pH value (measured 24 hours after slaughter) above 5.8. Concentration of lactate was measured both in plasma and muscle. Blood samples were taken before and after transport and the concentration increased by the factor of 1.03 to 4.22 after transport.

The measured vibration data was subjected to spectral data analysis to determine the main resonance frequencies. The identified resonance frequencies are at about 1.3, 3, 6, 12, 25 and 40 Hz. The first two frequencies are typical for animal transporting trucks. The variation of resonance frequencies depended on vehicle's speed and road type and further investigations should be made to scrutinize the effect of the identified frequencies on animals.

Investigation on the effect of vibration magnitude on heart rate and pH-value showed that an increase of r.m.s acceleration by about 5 times caused an increase of heart rate by 80% and the meat pH-value of those animals transported on rough and curved roads was above 5.8. However, further comprehensive investigation is required to determine the effect of vibration on the final pH of meat.

The route planning and optimization for each journey was made using a network software, DPS. Route optimization decreased the actual transport distance by 8% to 14%. Air emissions such as CO₂, CO, HC and oxides of nitrogen from the vehicle were computed using MODTRANS, the model developed for food distribution and environmental research. Route planning could reduce air emissions by 10% to 18%.

The current work recommends to carry out detailed investigations on the effect of transport length and vibration on heart rate and meat quality of various categories of animals. Application of route planning is also recommended to reduce the transport distance.

1. Introduction

1.1. Back ground

Due to the dynamic structural change in production systems and patterns of people settlement, human, animal and goods transport, especially long range transport, is substantially increasing at a high rate nowadays.

Millions of animals are transported from farms to farms and from farms to abattoirs every year in Sweden. Only at the Uppsala section of Scan Farmek about 50 000 ton live weight of animals are transported for about 1300000 km per year. In relation to rationalization, the number of abattoirs have been halved in the last 20 years and the process of centralization continues. The recent structural change in centralization of abattoirs and closing down of many abattoirs implies that the animals should be transported greater distances and transport work intensifies to meet the requirements of the new system.

During handling and transport, the animals are subjected to discomfort, inconvenience and a potential stressful situation due to mechanical vibration, noise, environmental constraints in the vehicle, social grouping in the vehicle, and this compromises animal's welfare and also leads to loss in terms of meat quality and mortality.

The other issue associated with an increase of transport work, which became among the main concerns of the Swedish society, is the environmental devastation due to air emissions from the vehicles.

The transport and handling system, with its inputs and outputs, is idealized in Figure 1. Loading of animals at the farm, social grouping, stock density, trucks performance, road conditions, transport time length, climatic conditions in the truck, un-loading performances, waiting time at the abattoir prior to slaughter are considered to be the main input factors in the system determining the state of animal welfare, meat quality and the environment. The three vital issues, i.e., animal welfare, meat quality and environment are not the issues to be compromised.

The Department of Agricultural Engineering of Swedish University of Agricultural Sciences has initiated a research programme to scrutinize transport and logistics in the agricultural sector in relation to environment, energy and economy. Within the range of the programme, SLU and Scan Farmek developed a collaborative project to conduct a comprehensive study on the transport of cattle.

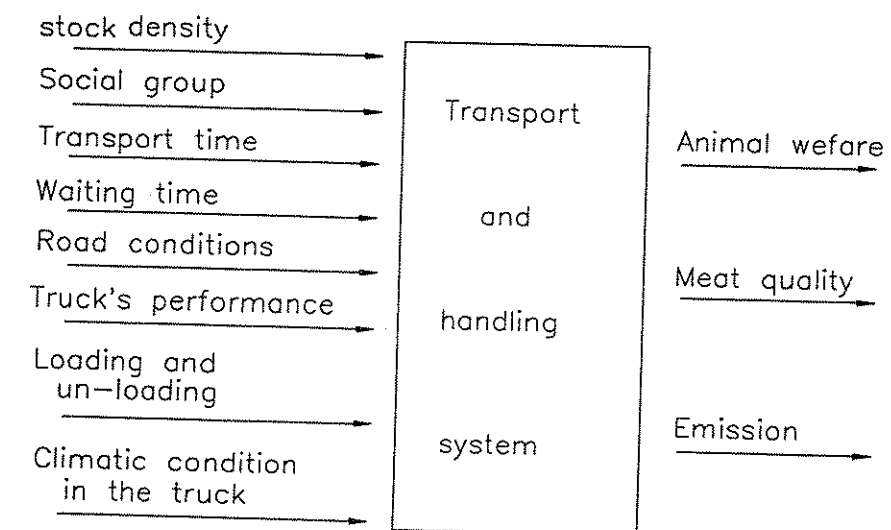


Fig. 1. Factors which may affect meat quality, animal welfare and environment in the transport and handling system

1.2. Literature review

Transport of slaughter animals is associated with series of events which cause stressful and unfavourable conditions on animals compromising the welfare of animals and finally leads to reduced meat quality. The level of animals response to the stress imposed on it may depend on the animals perception on both the previous and present conditions (Gross and Siegel, 1993). Kent and Ewbark (1983) classified transport and handling events into five main components: original environment (i.e., environment at the farm), loading, transport, un-loading and the new environment at the abattoir. Kenny and Tarrant (1987) studied the effect of those events under transport process using young cattle. The specific events considered were repining, stationary confinement, loading, unloading and confinement in a moving truck. It was reported that confinement in a moving truck was the most stressful process for the cattle.

Tarrant and Grandin (1993) summarized many useful research reports made earlier on the effect of transport on behavioural and physiological parameters. The pertinent physiological parameters used as indicators of stress to study the response of animals to transport were heart rate, blood composition such as hormones and enzymes, and live weight. Tarrant and Grandin (1993) noted that the available data on animal transport was limited and recommended further comprehensive investigations.

Behaviour

The alteration of behaviour of animals have been used by many researchers as stress indicator. Broom (1993) emphasised that the most common indicator that an animal is having difficulty coping with handling and transport is change in behaviour which show that some aspect of situation is advertise. Gonyou (1993) gave an account on the behavioural principles of animals during handling and transport by making a comprehensive assessment on the earlier literature. He noted that method of animal handling should be determined taking into consideration factors such as animals previous experiences, facilities and personnel involvement and the normal behavioural characteristics of the species.

Wythes et al (1988) studied the effect of duration of rest and nature of resting conditions on carcass weight, bruising and muscle properties of cattle after 125 km road journey. The cattle were allowed to rest for 2.5 hr or 26.6 hr and had access to water until slaughter. It was reported that neither resting time nor resting conditions had effect on bruising of cows, while steers rested for 26.5 hr had a higher mean bruise score than those animals rested for 2.5 hr. Cockram (1991) scrutinized the resting behaviour of 130 cattle in a slaughterhouse lairage. The moving, standing and lying behaviour of cattle in a lairage pen was observed using a video camera mounted above the pen. Cockram reported that the number of cattle lying down increased with an increase of duration in the lairage.

Mohan Raj et al (1991) investigated the behavioural response of bulls and steers to mixing. The occurrence of aggressive (butting and pushing) and sexual (teasing and mounting) behaviours were recorded using a portable video camera continuously under the time of mixing. The authors concluded that the behavioural interactions between groups depend on their temperament. Bradshaw et al (1996) studied the effect of mixing and duration of journey on the behavioural and hormonal response of pigs. The parameter measured was salivary cortisol. It was reported that mixing of pigs caused a significant increase of level of salivary cortisol.

Transport time length

Transportation time length may have significant impact on animals. Very limited studies have been made to determine the effect of short haul and long distance (Kenny and Tarrant, 1987; Knowles et al 1993; Möller et al, 1994). Möller et al (1994) investigated the effect of transport time on pH value of meat. According to the reported result, almost all animals transported between one and six hours had a pH above 5.8. Fernandez et al (1996) assessed the influence

of transport time length on the live weight and pH using calves. The authors reported that long transport of 11 hours resulted in decreased live weight by 3.6% and increased muscle pH. The reported weight loss may be in general attributed to dehydration (Tarrant et al (1992).

Stock density and social group

The size of pen, stock density and mixing with un-familiar animals may have negative impact on animals. Carlsson (1985) studied the impact of stock density and social group on pigs behaviour during transport. He reported that both factors caused an increase of violent aggression and bruising, and recommended the avoidance of mixing of animals. Becker et al (1988) cited the work of Warris and Brown (1985) where they reported that the act of aggression altered concentration of lactate in the blood and pH of the meat. Several studies have also been made on the subject in the late 80s and in the 90s (Eldridge and Winfield, 1988; Guise and Penny, 1989; Guise and Warris, 1989; Bradshaw et al, 1996; Cockram et al, 1996). However, it may not be easy to draw a general conclusion from the reports.

Meat quality

Poor pre-slaughter handling including transport may prejudice animal welfare and reduce (Warris, 1993). Meat quality is usually evaluated in terms of the occurrence of PSE (Pale, Soft and Exudative) and DFD (Dark, Firm, Dry) and pH is used to determine DFD meat (Hails, 1978; Lundström et al, 1980; Grandin, 1980; Malmfors et al, 1983; Fabiansson et al, 1984; Lundström et al, 1987; Warris, 1987; Malmfors and Bredov, 1988; Möller et al, 1994). Malmfors et al (1983) studied the effect of size of pen on the incidence of DFD and reported that the use of individual pen instead of large and free-range pen reduced considerably the incidence of DFD. Similar studies made later (Warris, 1987; Wythes et al, 1988; Cockram, 1991) confirmed the above result.

The pre-slaughter breakdown of muscular glycogen to lactate and post-mortem depletion of glycogen results in high pH in the meat causing the occurrence of DFD (Fabiansson et al 1984) and pH is considered to be important meat quality parameter and the best indicative of DFD. Warris (1993) noted that the main attributes of meat quality are the colour, water-holding capacity and palatability of the lean. He emphasized further that the combination of several stressor deplete muscle glycogen to low enough levels where ultimate pH is elevated and produce DFD meat.

However, different researchers recommend different limits of pH to characterize DFD. Fabiansson et al (1984) summarized the recommendations of experts and researchers on the pH limits for DFD meat and in many cases meat with pH values of 5.8 and above is classified as DFD meat (Tarrant and Grandin, 1990). Some investigation made earlier in Sweden (Möller et al, 1994) showed that about 10% to 25% of beef meat, specially from young bulls and calves has developed DFD (i.e., meat with pH more than 5.8).

Loss of balance and vibration

In the course of transportation from farms to abattoirs, animals are subjected to vibration, noise and environmental variations in the containers, and these factors are considered to be the acute stressor causing physiological and behavioural-stressful (Stephanes and Rader, 1983). Vibration induced by the motions of vehicles adversely affects health, comfort, activities and causes motion sickness (BSI, 1987).

During transport, particularly on rough surfaced roads, the transmission of the vehicle's floor vibration to the animals could be significant and it may create uncomfortable conditions by causing the displacement of centre of gravity of an animal resulting in the body disturbance (Randall, 1992; Randall et al, 1995).

Loss of balance of animals on a moving vehicles may be caused by the performances of the vehicle (variation of speed and vibration) animal's standing orientation in the vehicle, road conditions (roughness, undulation and road curvature). Tarrant et al (1992) studied the effects of stress inducing vehicle's performances such as braking, gear changes, starting and stopping, cornering and bumping on the loss of balance of cattle transported under 24 hrs. According to their report, about 80% of the loss of balances was caused by braking, gear changes and cornering.

Attempts have been made to apply the degree of vibration and human response to animals. However, because of the difference in morphology, body mass and stance, it may not be possible to use on animals the optimum ranges of vibration determined for human (BSI, 1987; Randall, 1992; Randall and Mehan, 1993; Randall et al, 1995; Stephens and Perry, 1990). Important research reports have made on the effect of body vibration on poultry (Ruther and Randall, 1993; Grham, 1994; Scott, 1994; Duggan et al, 1995). Though results from these works are useful, it may not be possible to use them for cattle.

Heart rate

Behavioural and physiological changes are responses to stressor (Gross and Siegel, 1993). In many cases variation of heart rate is used as a measured of physiological response and welfare particularly for short-term stresses. Broom (1993), in his assessment, noted that even in the absence of behavioural response, changes in heart rate and adrenal activity may occur.

Stephens and Rader (1983) have studied the effect of vibration, noise and restraints on heart rate and blood pressure of pigs using a transport simulator. They have reported that heart rate of pigs significantly increased when the animals were subjected to vibration and noise and the renal blood flow reduced from 5 m/s to 2.5 m/s.

Kenny and Tarrant (1987), in their investigation on the response of young bulls to short haul road transport, measured heart rate at rest, post-treatment and after recovery for various treatments (re-grouping on a stationary and moving truck, confinement without re-grouping on a stationary and moving truck). The authors ranked the level stress caused by the treatments in the following descending order: confinement in a moving truck, stationary confinement and re-penning.

The effect of loading, un-loading activities and standing orientation on heart rate of horses was also examined by some researchers and reported that the process caused an increase of heart rate (Baldock and Sily, 1990; Warran, 1995; Warran and Cuddeford, 1995; Clark et al, 1993).

Warran and Cuddeford (1995) conducted a preliminary study on the effect of loading and transport on the heart rate and behaviour of 32 horses of under and over 3 years old. Measurements were taken when the horses were confined in a stationary vehicle and when transported for 25 minutes. The authors reported that the heart rate raised during loading for all groups, but no significant difference was observed among age groups. The heart rate increased by 18 beat per minute (on average) during transport in comparison to the stationary. They also noted that the horses forwarded and apart their forelegs and apart their hindlegs to maintain balance during transport.

However, little investigation of the afore-mentioned type has been made on beef cattle, and no continuous measurement has been made on heart rate either.

Effect of temperature

The environment in the compartments of animal transporting vehicle is an important issue to be considered both from animal welfare and meat quality points of view. Lambooy (1988) studied the effect of temperature and relative humidity variations on meat quality of pigs after a simulated international journey of pigs over a long distance of about 1500 km. The meat quality was determined using pH. It was reported that a higher compartment temperature caused an increase of pH.

In many cases, loss of weight of animals increased with an increase of temperature in the pens (Halls, 1978). Halls noted that the loss of weight during transport was attributed to increased evaporation from the skin and respiratory tract.

2. Objectives

The literature discussed above indicate that important works have been made in animal handling and transport in relation to meat quality and animal welfare. However, no work has been found on the continuous measurements of stress indicating parameters such as heart rate to determine the most stress inducing factors during handling and transport. No work has neither been done on the environmental impact of animal transport.

The general purpose of this study was to assess the slaughter animal transport from farms to abattoirs in order to search and provide pertinent information to develop an effective transport and logistic system using information technology to promote economy, animal welfare and environment.

The specific objectives were to:

- a) investigate and to identify stressful events and parameters which may have significant impact on animal-stress during handling and transport from farms to abattoirs and to provide sufficient information to improve handling methods and transport equipments

- in order to guarantee meat quality and animal welfare,
- b) scrutinize the transport route and conduct a route planning simulation and optimization, and
- c) determine the environmental impact of animal transport.

The parameters listed below were assumed to be the most pertinent parameters which should be considered to meet the objectives of the present work.

- (a) heart rate,
- (b) pH,
- (c) lactate and muscle glycogen
- (d) social grouping, stock density
- (e) temperature in the vehicle,
- (f) animal behaviour,
- (g) vibrations in tri-axial directions,
- (h) locations of farms in relation to the abattoir,
- (i) routes of transport, distance, time
- (j) transport speeds,
- (k) road conditions, and
- (l) air-emission from the truck

3. Materials and methods

3.1. Farms

To conduct the project, nine farms were selected and classified into three depending on their locations in relation to the Scan Farmek's abattoir in Uppsala and transport time, i.e., transport time under one hour, two hours and more than six hours.

3.2. Animals

For this phase of the project, forty five cows were used. The cows were used to be tied at the farms and were also tied during the transport. Five cows were used from each route and simultaneous measurements were made on each cow. All the five cows on which the measurement made were from the same farm.

3.3. Vehicle

It has been intended to use three vehicles of different loading classes to conduct the project in a full scale. However for this particular part of the project only one vehicle, Volvo FH12 (Fig. 2), was used. The truck is 12 metre long and weighs 14 tonne. It has four pens and the size of each pen is 2.54 m long and 2.37 m wide and accommodates four animals.



Fig. 2. Truck used for the experiment

The animals on which the measurement was carried out were placed in the first and second pens. The first pen is the pen near to the cabin. The maximum number of animals which can be loaded on the vehicle is 16, i.e., four animals in each pen. The maximum load (vehicle and 16 cows) is about 27 tonne and the average fuel consumption is about 4 litre per 10 km.

3.4. Instrumentation and parameters

A complex instrumentation system was developed at the Engineering department of Swedish University of Agricultural Sciences, SLU, to carry out the measurements of the parameters mentioned earlier simultaneously and continuously starting from the farm from where the animals were transported to the abattoir. Measuring equipments were mounted on the vehicle and the on-board instrumentation and the satellite steered position of the vehicles was controlled from the cabin of the vehicle (Figure 3). The instrumentation may classified into four groups (Fig. 4). Instrumentation for measuring (a) animal behaviour, (b) heart rate, (c) transport route, and (d) vibration and temperature. All groups were monitored using two on-board portable computers.

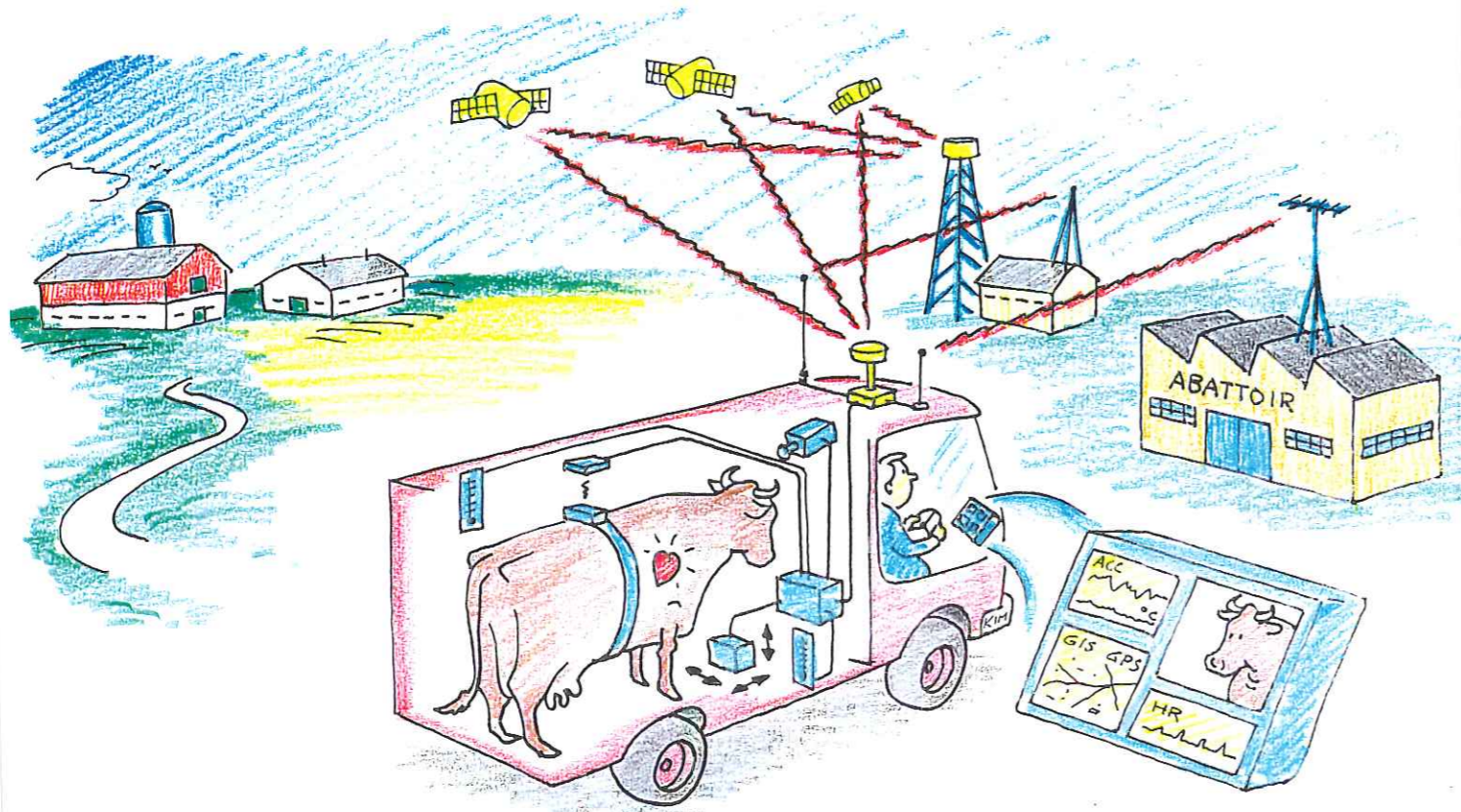


Fig. 3. Schematic presentation of transport and logistic system for slaughter animals transported from a farm to an abattoir

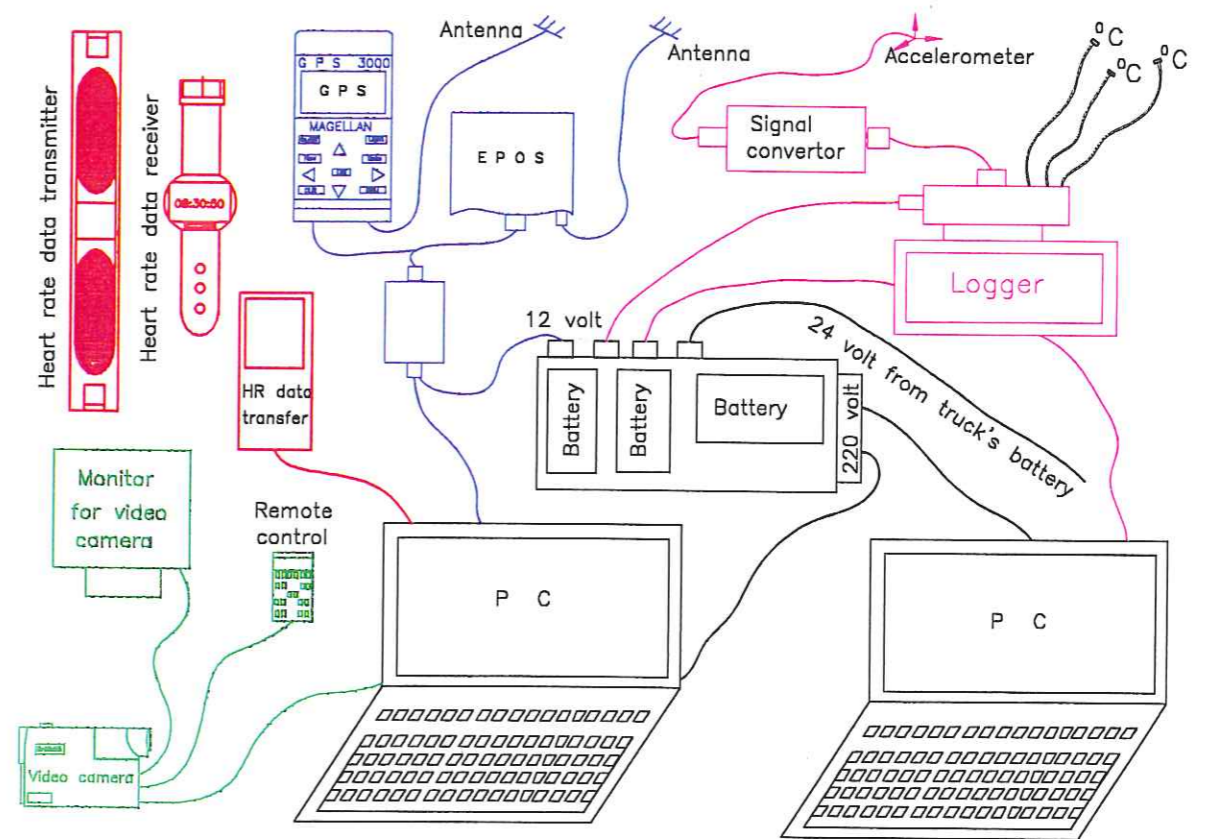


Fig. 4. Instrumentation used to evaluate the performances related to slaughter cattle transport. The instrumentation is classified into four groups.

Group 1: instrumentation to register the behaviour (it includes video camera, monitor and remote control);

Group 2: instrumentation to measure, store and transfer the animals heart rate (it includes belts associated with electrodes, data receiver (watch), sensor and data transferring equipment to the computer);

Group 3: instrumentation to determine the position and route of the truck (it includes GPS, DGPS (equipment for differential global positioning system) and antennas);

Group 4: instrumentation to measure the truck performance and environmental conditions (it includes three dimensional accelerometer, temperature sensor, signal convertor and data logger)

3.4.1. Heart rate

The heart rate of the animals was measured continuously throughout the handling and transport time (before loading at the farm, during loading, transport and un-loading at the abattoir). Data of the heart rate was collected simultaneously on five cows for each route and the data was sampled at the rate of 0.5 Hz. Detailed description of the instrumentation is given elsewhere in the literature (Polar, 1996).

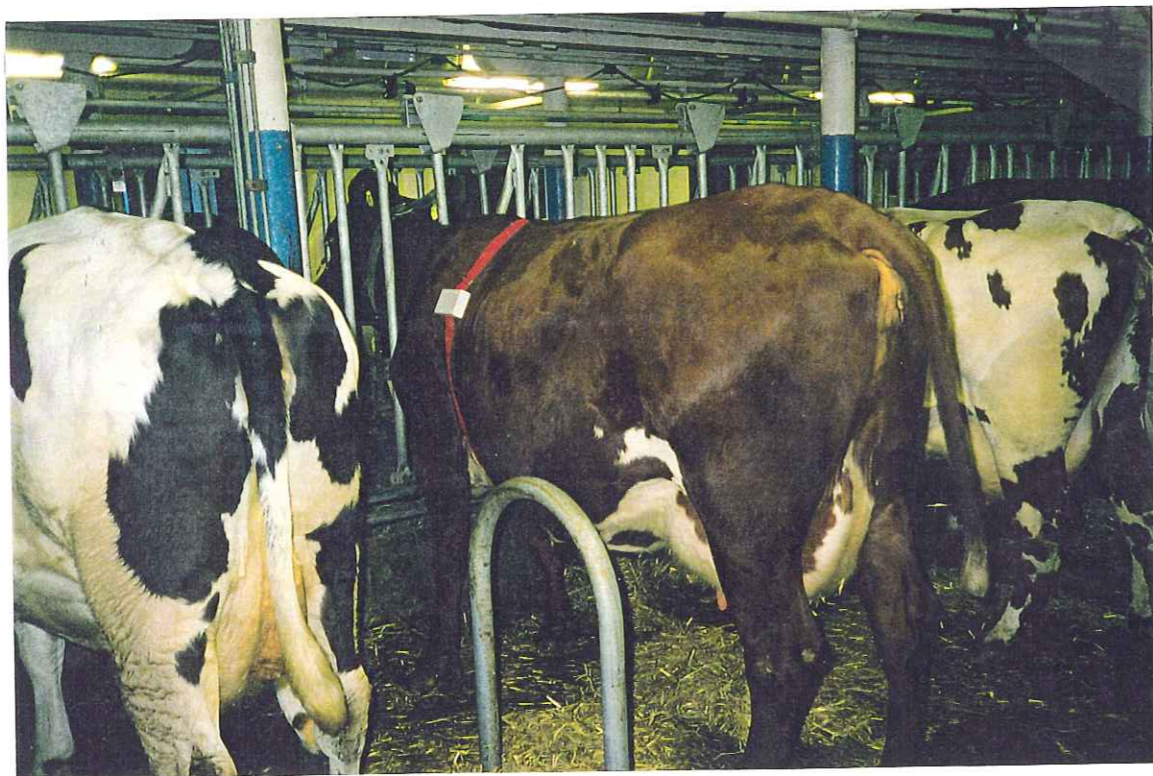


Fig. 5. Heart rate sensor and receiver mounted on a cow

The main components of the instrument are, signal sensor (mounted on each cow very near to the heart as shown in Figure 5), remote signal receiver (placed in a plastic box for protection and the distance between the sensor and the receiver should not be more than 1000 mm) and data transferring component from signal receiver to a computer. Both the data transfer and receiver were mounted on the animals using an elastic belt (Fig. 5).

3.4.2. Meat quality

Lactate concentration in the blood and muscle, muscular glycogen concentration, and pH were used as indicators of meat quality. Measurements for lactate concentration were made before and after transport. Samples for pH were taken at 45 minutes, 12 hrs and 24 hrs after slaughter.

3.4.3. Animal behaviour

Observation on the alterations of animals behaviour when subjected to various stressing and uncomfortable physical activities was made using a digitized video camera continuously throughout the loading, transport and un-loading processes. The camera was mounted in the first pen and able to film clearly the animals in the second and third pens.

The standing orientation of the cows was perpendicular to the direction of vehicles motion. The adjacent animals were faced in the opposite direction to each other and all were tied throughout the transport time.

3.4.4. Vibration

The effect of vibration on animals depends on many factors, such as acceleration magnitude, frequency spectrum, direction of action, position of contact, duration, posture and orientation of the body (Randall, 1992). To quantify most of the mentioned factors, a tri-axial and high precision accelerometer with a range of $\pm 98 \text{ m/s}^2$ and a frequency response of 0 to 350 Hz were mounted on the floor of the second pen (where the test animals were placed). The measurements were taken for different speeds of the vehicle on different road types. The resonance frequency of the accelerometer was 22 kHz.

3.4.5. Temperature

As mentioned earlier in the text, variations of climatic conditions such as temperature and humidity in the vehicle are among the main factors causing uncomfortable conditions for the animals during transport. To observe the variation of temperature, three temperature sensors were placed in the pens (one in the first pen and two in the second pen).

3.4.6. Transport route

To measure the transport routes, the Global Positioning System, GPS, database for digitized maps and optimizing software, DPS, were used. For the measurement of the route and location of the farms, GPS signal receiver GPS 3000XL was used. Using GPS signal receiver, latitude, longitude, altitude and vehicle's speed were measured. Altitude was measured to determine the slopes of roads.

The vehicle's route and positions of each visit place (farms, abattoir and transport company) were determined using GPS. The portable GPS equipment receives signals from three satellites and determine the position using the intersection of the three cones of the satellites (Bernhardsen, 1992). The accuracy of the measured data can be improved by the method called Differential GPS. According to the method, data received simultaneously by two signal receivers from the satellites were used (Fig. 6). The co-ordinates of one of the receivers should be known, and then the correct co-ordinate of the second position can be calculated. The level of accuracy used for the present work was $\pm 5 \text{ m}$.

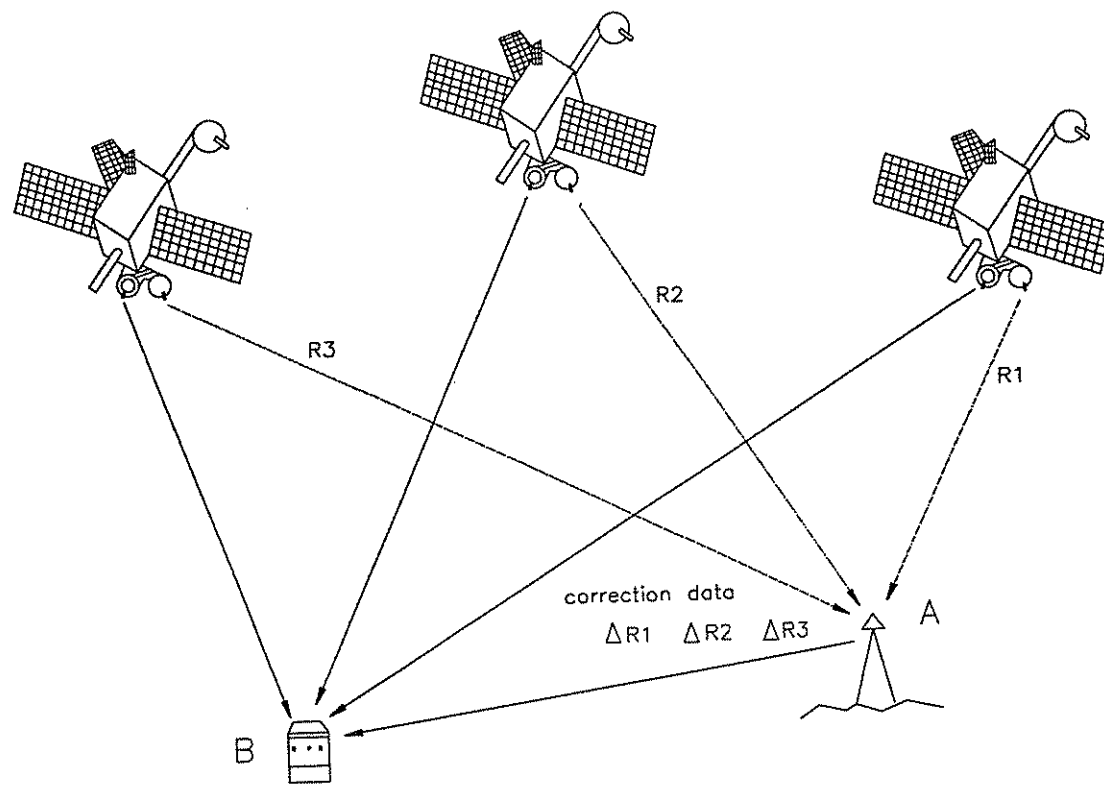


Fig. 6. Differential Global positioning system, DGPS. B denotes GPS signal receiver on the truck while A denotes a stationary signal receiver whose latitude and longitude are known (Bernhardsen, 1992)

3.4.7. Air emissions

Air emissions from the vehicle were determined during the studies. For the emission calculation, it was necessary to take into consideration the total distances, i.e., distance from vehicle park of transport company to farms and to the abattoir and thereafter back to transport company. During transport, factors such as road conditions, vehicle's speed, load at each interval of stops, duration of stops (duration of motor's idle running), road conditions and slopes were considered. The speed of the vehicle was determined using the GPS signal receiver.

MODTRANS (Gebresenbet and Oostra, 1997), the model describing the material flow and air emission, was used to determine the transport work for each route and air emissions such as carbon dioxide, carbon monoxide, hydrocarbons and oxides of nitrogen.

4. Result and discussions

4.1. Heart rate

As mentioned earlier, continuous measurements of heart were made on five cows from each farm. The measurement started at the farms prior to loading and continued until slaughtering. The typical output result is presented in Figure 7. As it can be observed from Figure 7, the heart rate increased from about 45 bpm to about 108 bpm during loading (separation of the animal from its group and forcing the animal to clamp the ramp into the truck). The slope of the ramps varied from 16° to 28° depending on arrangements at the farms. During loading, it was observed that the animals were reluctant to climb the steeply ram. As quoted by many authors (Broom, 1993, Tarrant and Grandin, 1993) the work of Putten and Elshof (1978), the heart rate of pigs increased by a factor of 1.65 when they were made to climb the ramp. According to Trunkfield and Brom (1990) the heart rate increased by 80 bpm when calves were transported for one hour.

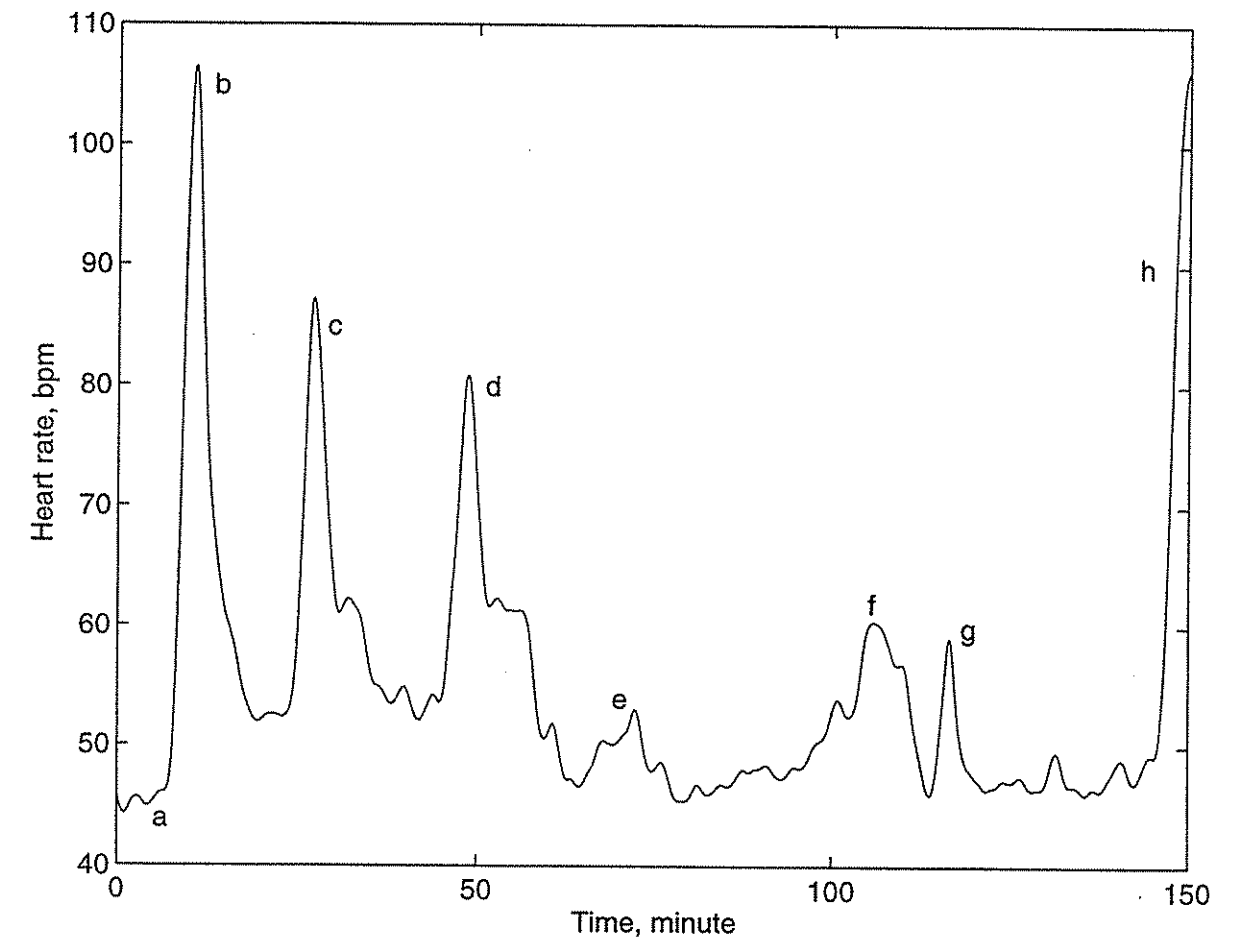


Fig.7. Typical measured heart rate profile during handling and transport. The measured data positions in the plot indicated by letters are heart rate values: a, animal at the farm before loading; b, loading of the animal on the truck; c,g, the vehicle starts moving; d,f, mixing with un-familiar animals i.e., when loading other animals from other farm (d and f denote the second and the third farm respectively); e, transport on the rough road; h, un-loading at the abattoir

The heart rate falls and stabilizes as soon as the animal is tied and maintain its position in the pen (Fig. 7). The heart rate again rises as the vehicle starts its motion. Being transported and subjected to motion is un-familiar conditions for the animals and therefore cause stress on the animal. After a while, it looks that the animals soon adapt to the new environment and the heart rate again falls. However, when the vehicle rides on a rough and curved roads the variation of heart rate is significant (the coefficient of variation ranges between 0.11 to 0.35).

Another heart rate peak occurred (Fig 7 denoted by f) when animals met un-familiar animals from another farms. Many scientist recommended avoidance of mixing with strange animals prior to slaughter. However, it is very unlikely that animals only from a single farm transported to an abattoir without mixing them with other animals. The most usual procedure is that the driver collects animals from different farms and transport them to the abattoir. Warris (1993) stated that "the major cause of DCB is mixing unfamiliar cattle but other factors influence the extent of the problem and these are little understood."

The final and almost similar in magnitude with the loading peak is the peak at the abattoir. The animals might be scared of un-familiar environment (noise at the abattoir and its structure). Animals which were allowed to walk directly without making abrupt change of direction after leaving the truck were less stressed than those animals which were forced to make almost 90° turn after leaving the ramp.

It is worth to mention that, at some farms, the floor is slippery and the animals usually fall down on the way to the ramp. In Figure 8, letter b denotes the heart peak attributed to the effect of slippery surface of the floor.

The series of events where transported animals are usually induced may be summarized as follows:

- a) separation from groups at the farm,
- b) forcing animals to clamp up the ramp into the truck,
- c) confine them in truck where motion is limited,
- d) as the truck starts moving animals are subjected to motions,
- e) vibrations in different directions (vertical vibration due to road roughness, horizontal vibration due to speed variations, lateral vibration due to variations in the curvature of roads),
- f) mixing with strange animals from other farms,
- g) un-loading at the abattoir.

4.2. Effect of social group on heart rate

Comparison between the measured heart rate on different animals transported without mixing them with un-familiar animals and those transported and mixing with animals from other farms. The result depicted those animals mixed with other animals from other farm had higher heart rate than the others by the factor of 1.3. Though there is significant difference in amplitudes of heart rates, the peaks caused by other events identified maintained similar patterns (Fig. 9).

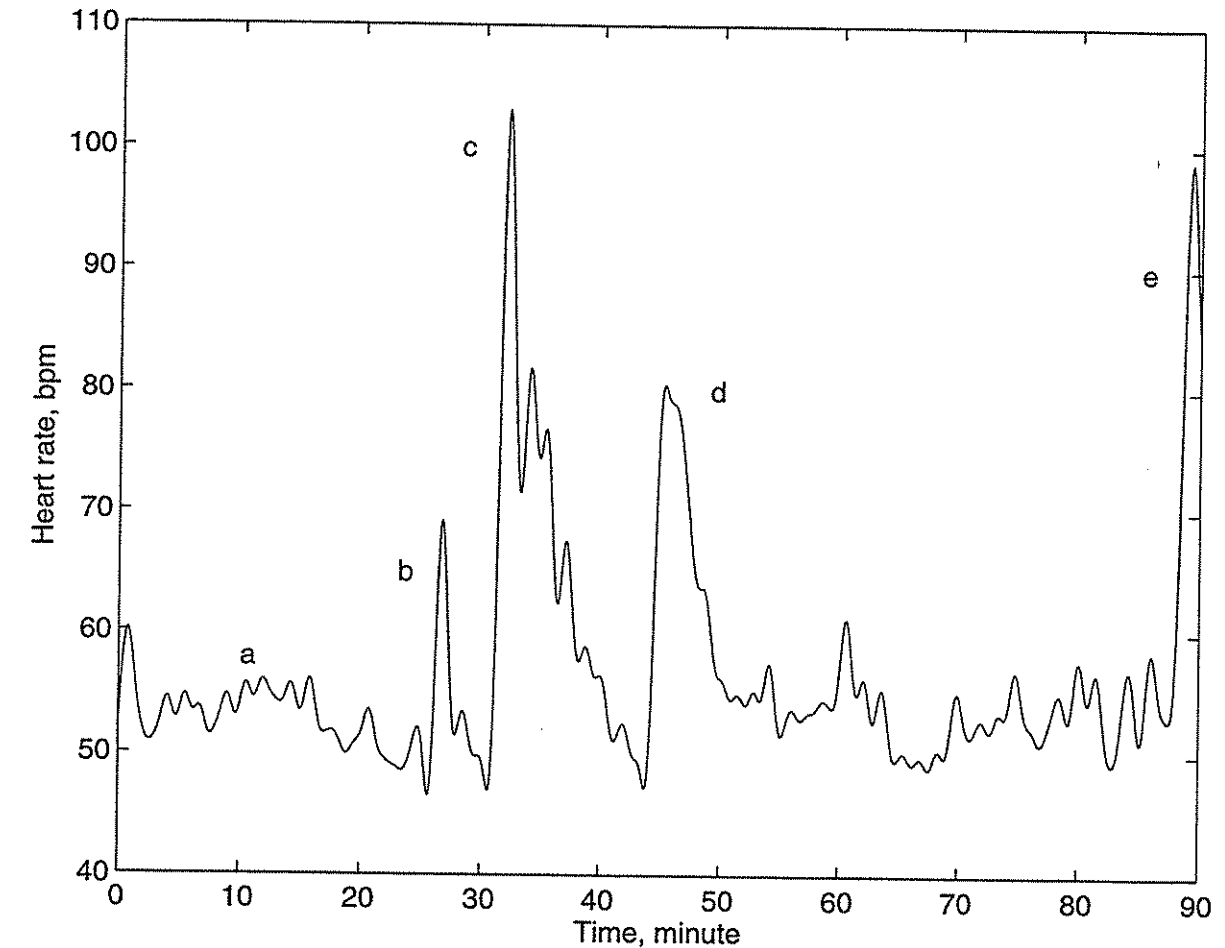


Fig. 8. Heart rate variations when the animals were transported directly from the farm to the abattoir without mixing them with other animals. The letters in the a, b, c, d and e are denoting heart rate of the animal before separating from its group, animal falls because the floor was slippery, animal mounting the ramp to enter the vehicle, vehicles initial motion and un-loading at the abattoir respectively.

However, this result should be considered as preliminary because only 16 animals were used for this part of the experiment and therefore further investigation may be recommended using more number of animals.

4.3. Meat pH-value

As described earlier, measurements for the pH level were made in three steps. The first, second and the third measurements were made at 45 minutes, 12 hours and 24 hours respectively after slaughtering. In many cases, the pH falls rapidly between the first and the second measurements and maintain its steady state after 15 hours as shown in Figure 10. The measured points could be described using an exponentially decaying equation (Eqn 1),

$$pH = pH_0 e^{-at} \quad (1)$$

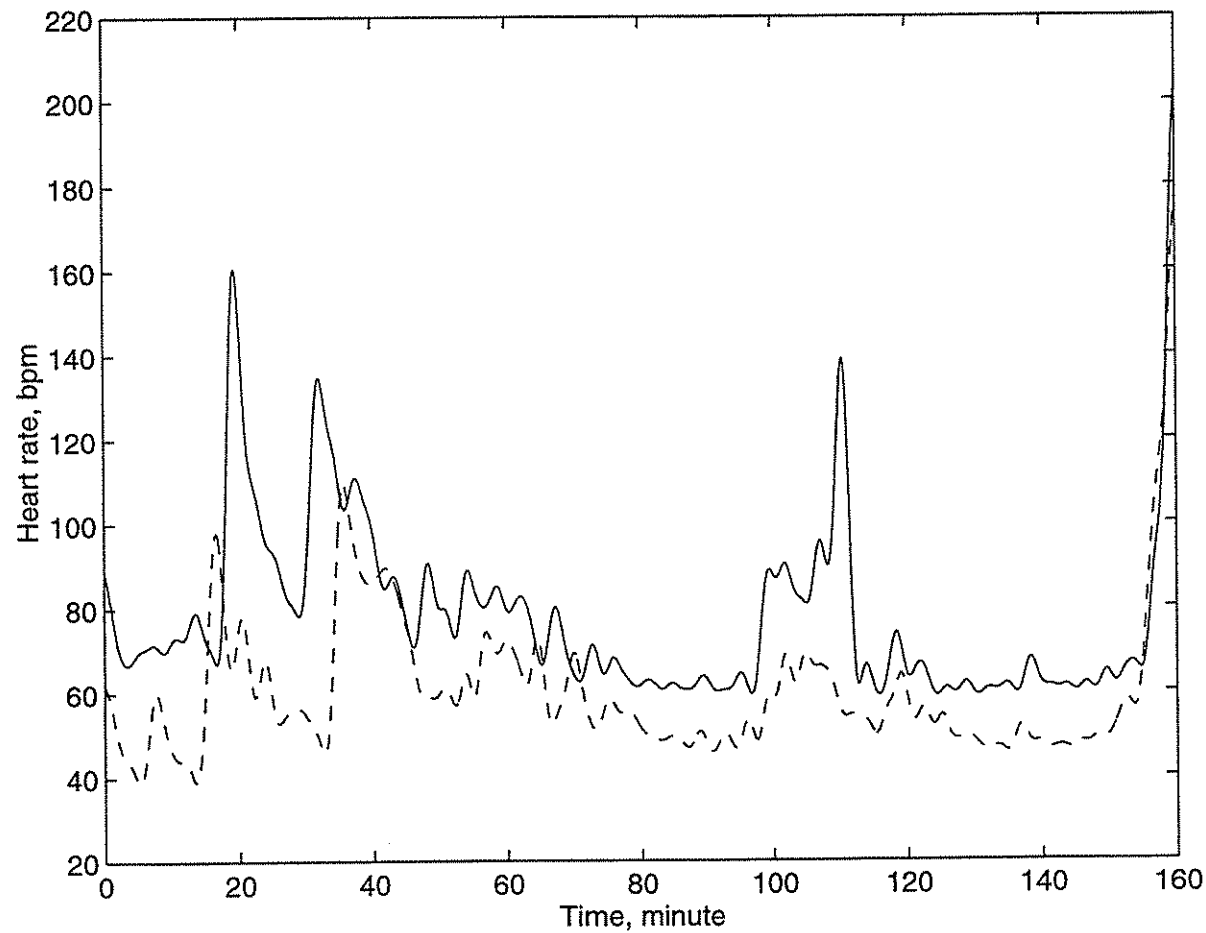


Fig. 9. Comparison between the measured heart rates on two animals. The full line depicts heart rates from the animal transported together with other animals from other farm and the dashed line denotes heart rate from animal transported with animals from the same group and the same farm. The measurement was made simultaneously

where pH_0 , a , and t are initial pH, constant and time respectively. The magnitude of the constant a varies depending on individual animals. However, there were cases where the pH decreased slowly and linearly from the first measurement to the third measurement. In this case the ultimate pH remained above 5.8.

The distribution of the final pH value (the pH value measured at 24 hours after slaughter) of all animals used for the experiment was assessed. As shown in Figure 11, about 20% of the animals had pH value more than 5.8, and about 67% of the animals had between 5.6 to 5.8. Only 3% of the animals had pH value of 5.5 and below. The animals which had the pH level of more than 5.8 were transported for 3 hours and most of the roads were have relatively rough surface and curved.

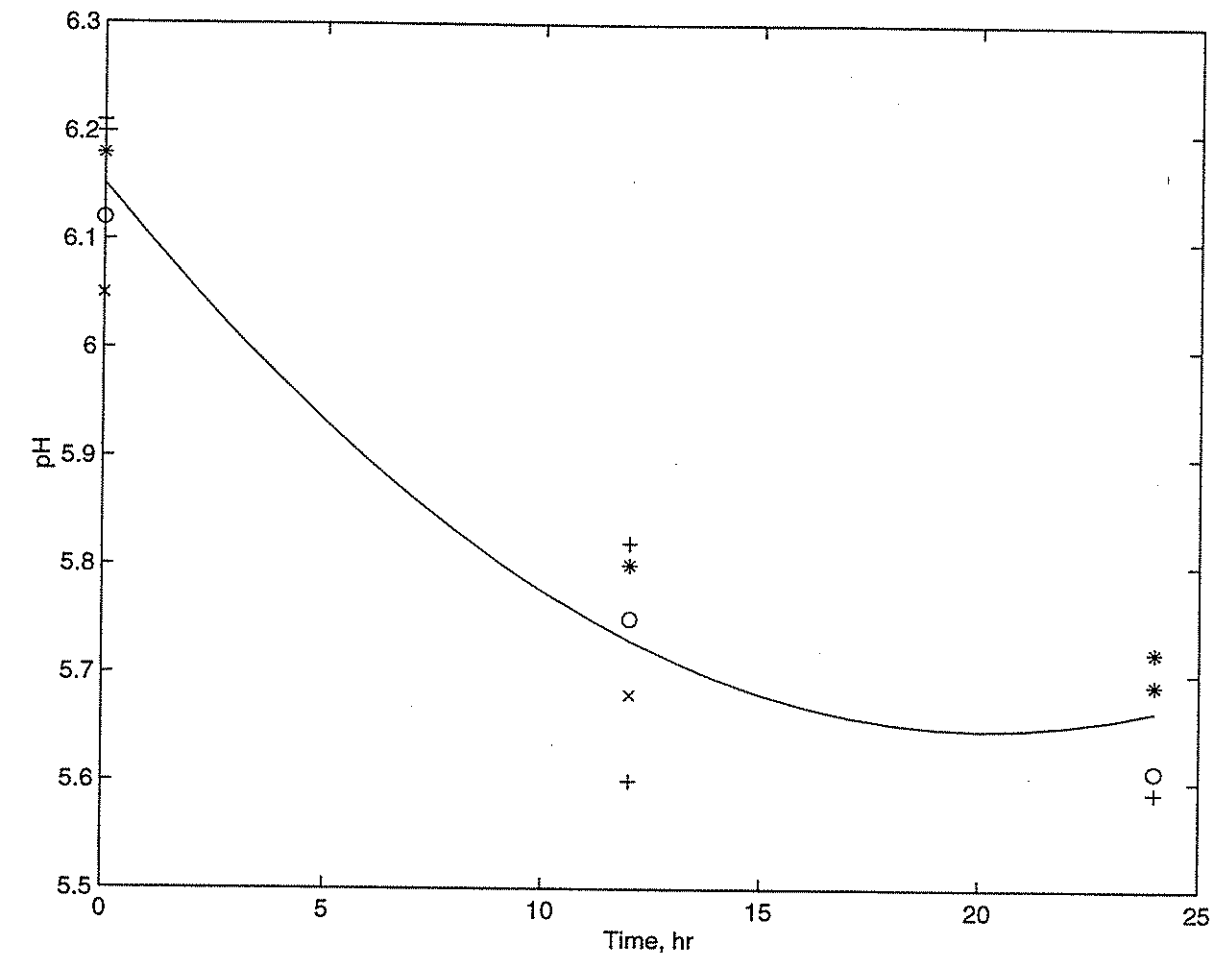


Fig. 10. Post-mortem pH development. The measured points for five animals are denoted by +, *, x, and o and the curve describes Eqn 1

Table 1 reports the development of pH of each animal and also compares the pH of five animals. It can be observed that the standard deviation of the initial pH of all animals is more than twice that of the ultimate pH.

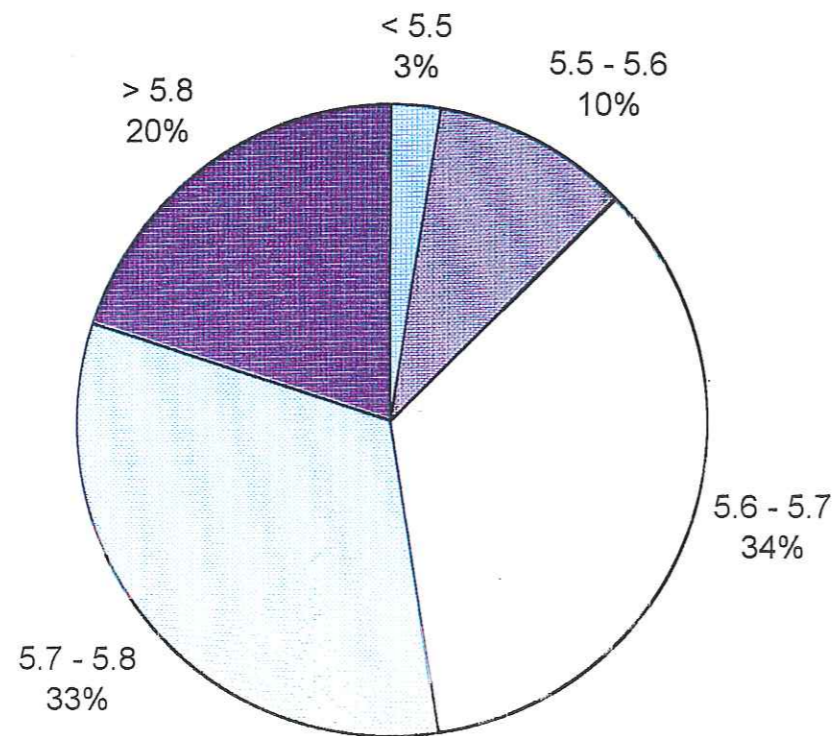


Fig. 11. Distribution of the final pH value of meat of the animals transported under various conditions

Table 1. Variations of pH among animals and development of pH of the same animal

pH	Animals					Standard deviation
	A1	A2	A3	A4	A5	
pH1	6.17	6.25	6.25	6.42	6.00	0.26
pH2	6.41	6.20	6.17	6.38	5.87	0.22
pH3	5.88	5.90	6.10	5.80	5.80	0.11
Standard deviation	0.42	0.19	0.14	0.17	0.10	

4.4. Lactate and glycogen concentration

Low concentration of lactic acid causes a high pH-value and the meat loses its quality. When ever an animal is subjected to either physiological or psychological stress, muscular glycogen breaks down to lactate (Lambooi and Putten, 1993; Tarrant and Grandin, 1993). Normally, after slaughter, muscle glycogen breaks into lactate thus to lactic acid leading to acidification of the meat (Warris, 1990). However, if the muscle glycogen depleted prior to slaughter due to stresses imposed on animals, the pH of the meat remains high.

As noted earlier in the report, lactate concentration in plasma and muscle was measured. Measurement for lactate concentration in blood was taken at the farm a day prior to the transport and after transport at the abattoir. Table 1 reports the results of the measurements made on 10 cows. Lactate concentration increased by factors ranging from 1.03 to 4.22 depending on individual animals and transport time. The first five cows were transported for one hour and 20 minutes while the remaining five cows were transported for 6 hours and 10 minutes.

The measured values of glycogen concentration in the muscle for animals A6-A10, in Table 2, are 272, 254, 283, 281 and 278 mg/100 g respectively. According to Möller and Borch (1991) meat with glycogen concentration of more than 60 mg/100g meat and pH value less than 5.8 maintains a good quality even after four weeks storage in relation to smell.

Table 2. Concentration of lactate, measured before and after transport

Animals	Lactate concentration, g/l	
	Before transport	After transport
A1	0.46	0.93
A2	0.67	0.76
A3	0.54	0.56
A4	0.59	1.66
A5	0.50	0.61
A6	0.21	0.83
A7	0.23	0.64
A8	0.37	0.50
A9	0.22	0.75
A10	0.18	0.76

4.5. Temperature

Temperature in the pens is another important factor to be considered during transport. For the current study, continuous measurements were made in three places in the pens. The result showed no significant variations of temperature (Fig. 12). The temperature differences between different position were not either significant. This is may be because, the air temperature outside the pens

was around zero degree Celsius and the ventilation system might be performed efficiently. Temperature variation could be considerable during summer where the air temperature outside air temperature is high.

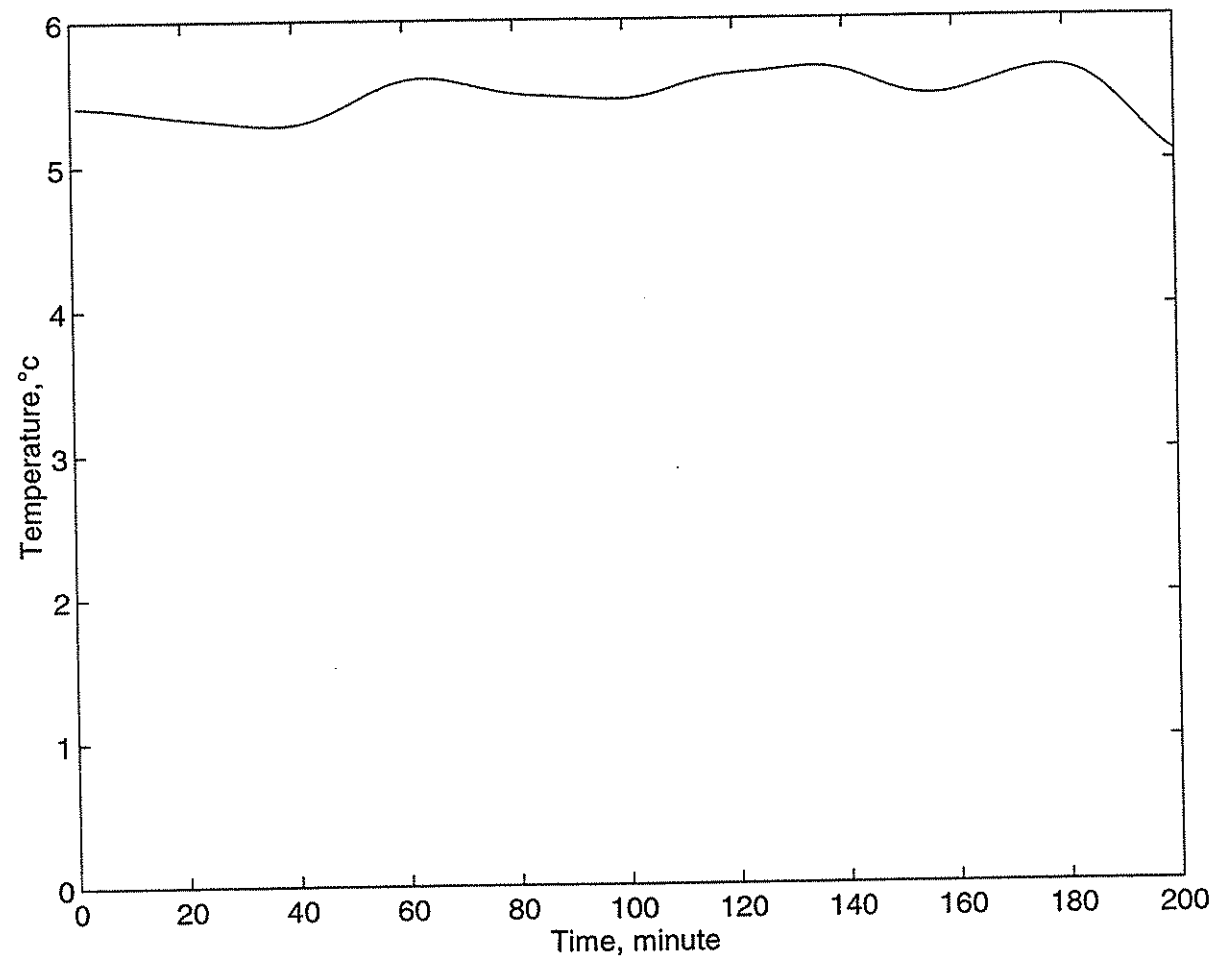


Fig. 12. Temperature variations in the pens

4.6. Behaviour

As mentioned earlier video records were used to observe the alteration of behaviour and loss of balance. As the animals were forced to climb the ramp and enter the vehicle, most of them urinated and started mooing. The stock density was $1.5 \text{ m}^2/\text{animal}$ or 467 kg/m^2 . The movement of animals were fairly restricted and there was small gap between the animals. In some cases, the animal stands between two animals couldn't lower its neck, because the rear of the animals from the left and right sides were already pressing each other.

As the vehicle started moving, the cows lost their balance and forced to rock strongly back and forth in the same direction as the vehicle's motion. All the cows in the same pen rocked together and the two animals at the outer sides in the pen collided with the walls of the pen. As soon as the vehicle increased its speed and riding on a curved and relatively rough surfaced road, the animals were forced to rock violently in the perpendicular direction to the vehicle's motion.

Vibration in both directions (parallel and perpendicular to the direction of motion of the vehicle) reduced significantly when driving on asphalted and straight roads with relatively constant speed. The level of rocking in the horizontal direction, the same direction as the vehicle, depends mainly on the operator's performances (speed variations, i.e., braking and acceleration).

During un-loading at the abattoir, all animals were reluctant to leave the truck. Defecation, urination, mooing, waving with their ears, exploration and tension on the legs were among the frequent behaviour observed.

4.7. Vibration of the vehicle

The discomfort produced by vibration during transport depends on the magnitude and frequency of vibration, body posture and orientation of the cattle and duration of vibration. The vibrations induced by road roughness, engine and driving performances were quantified using three accelerometers mounted in three mutually perpendicular directions (horizontal, lateral and vertical) and digitized at the rate of 200 Hz. The measured data was normalized to eliminate the effect of offset.

Frequency analysis was made using the power spectral density function to identify the dominant frequency composition of vibration data sampled for different road conditions and driving speeds.

Figure 13 illustrates the power spectral density of the data collected for a constant vehicle speed of 85 km/h driven on asphalted and relatively straight road. Three main resonance frequencies were identified for the vertical direction at 1.3, 5.1, and 12.6 Hz and a secondary peak at about 23 Hz. For the lateral and horizontal directions, the main resonance frequencies identified are at 11 and 26 Hz respectively.

Figure 14 reports the experiment made on the effect of a curved road on levels of vibrations. The amplitude of vibrations in the horizontal and lateral direction (perpendicular to the motion of the vehicle) are more than the vibration in the vertical direction. The main resonance frequencies are at 5, 12 and 30 Hz. For the lateral direction, a significant resonance frequency can also be observed at 40 Hz.

To study the effect of vehicle's speed on the level of vibration, the vehicle was driven at various speeds (ranging from 20 to 90 km/h). The identified resonance frequencies are at about 2.5, 10, 19, 32 and 40 Hz (see Figure 15). However, the resonance frequencies of vehicle for pig transport found by Randall (1993) for United Kingdoms road conditions were at 3, 9 and 20 Hz. Referring to the earlier reports, Randall noted that the resonance frequencies around 1 to 3 Hz are typical for livestock vehicles.

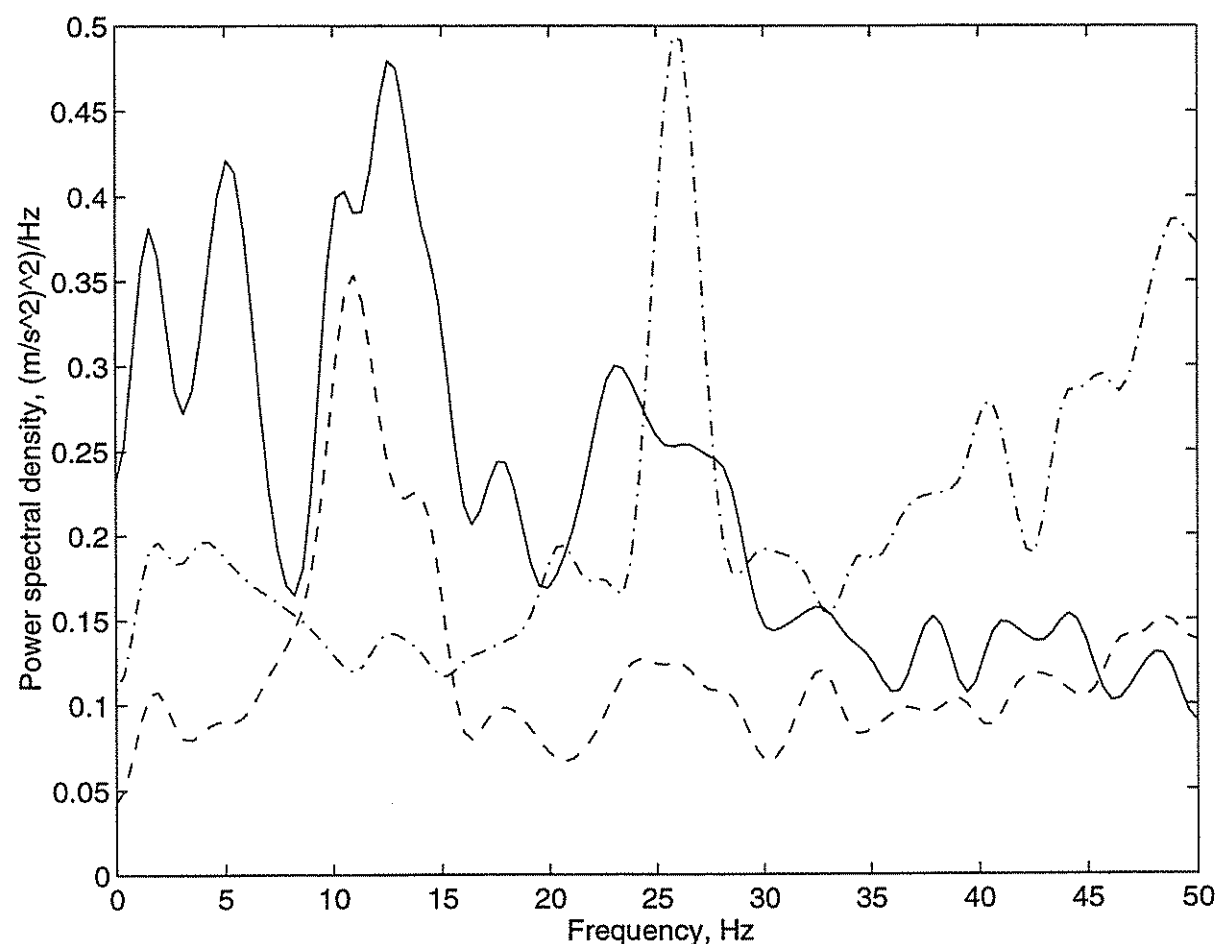


Fig. 13. Power spectral density of vibrations. The dashed, full and dotted lines denote lateral, vertical and horizontal directions for asphalted road and vehicle's speed of 85 km/h

The root mean square acceleration (r.m.s.) is generally preferred, for its convenience of analysis, to estimate the magnitude and severity of vibration (Griffin, 1990). The rms acceleration was computed for all the three directions for various speeds. The samples were collected on the same road for all speeds (20, 40, 60, and 80 kmph) for 30 seconds with three replications. As illustrated in Figure 16, the rms acceleration increased exponentially with an increase of speed.

According to Griffin (1990) the acceptable magnitude of r.m.s. acceleration depends on the duration of exposure, and therefore recommended to utilize the vibration dose value (VDV) to determine the total severity of vibrations. The estimated time series vibration dose value is computed using the formula:

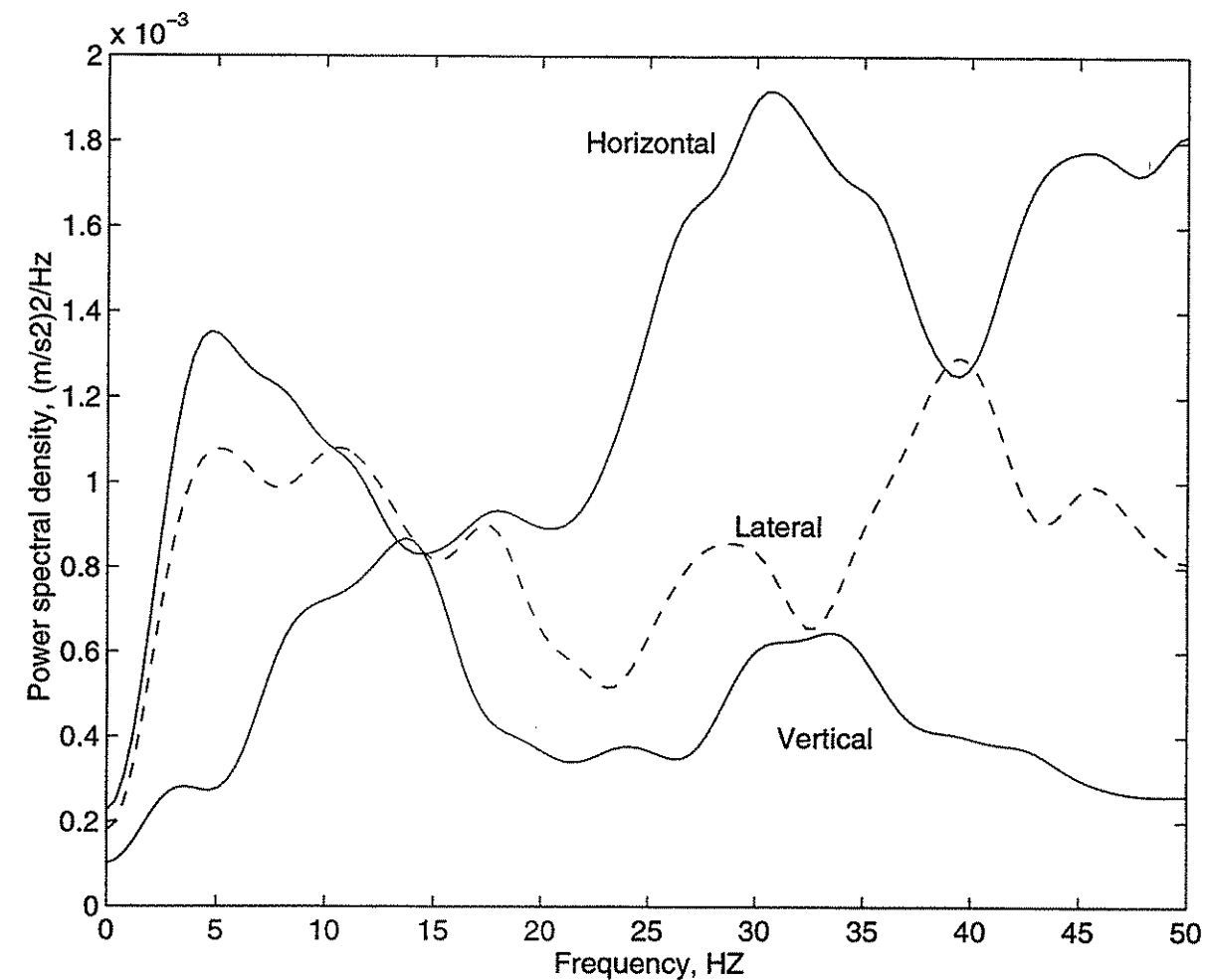


Fig. 14. Power spectral density of vibrations in the tri-axial direction when the vehicle rides on a curved roads

$$eVDV = [(1.4R)^4 T_s]^{1/4} \quad (2)$$

where T_s is sampling duration, and R is determined from: $R = \left[\frac{1}{N} \sum x_i^2 \right]^{1/2}$, where N is number of samples. The computed eVDV are reported in Table 3. The figures of eVDV for the vehicles speed of 60 kmph and above are adverse.

Table 3. Estimated vibration dose value, in time series, in tri-axial direction, i.e., vertical, horizontal (the same direction as the direction of motion of the vehicle) and lateral (perpendicular to the direction of the vehicles motion) for various vehicle's speeds on the same road.

Speed, kmph	eVDV m/s^2		
	Vertical	Horizontal	Lateral
20	0.83	1.11	1.05
20	1.07	1.24	1.34
40	2.35	3.02	2.239
40	2.87	3.34	2.59
60	3.01	3.94	4.37
60	2.46	2.69	3.69
80	5.11	9.81	9.53
80	5.39	11.65	9.21

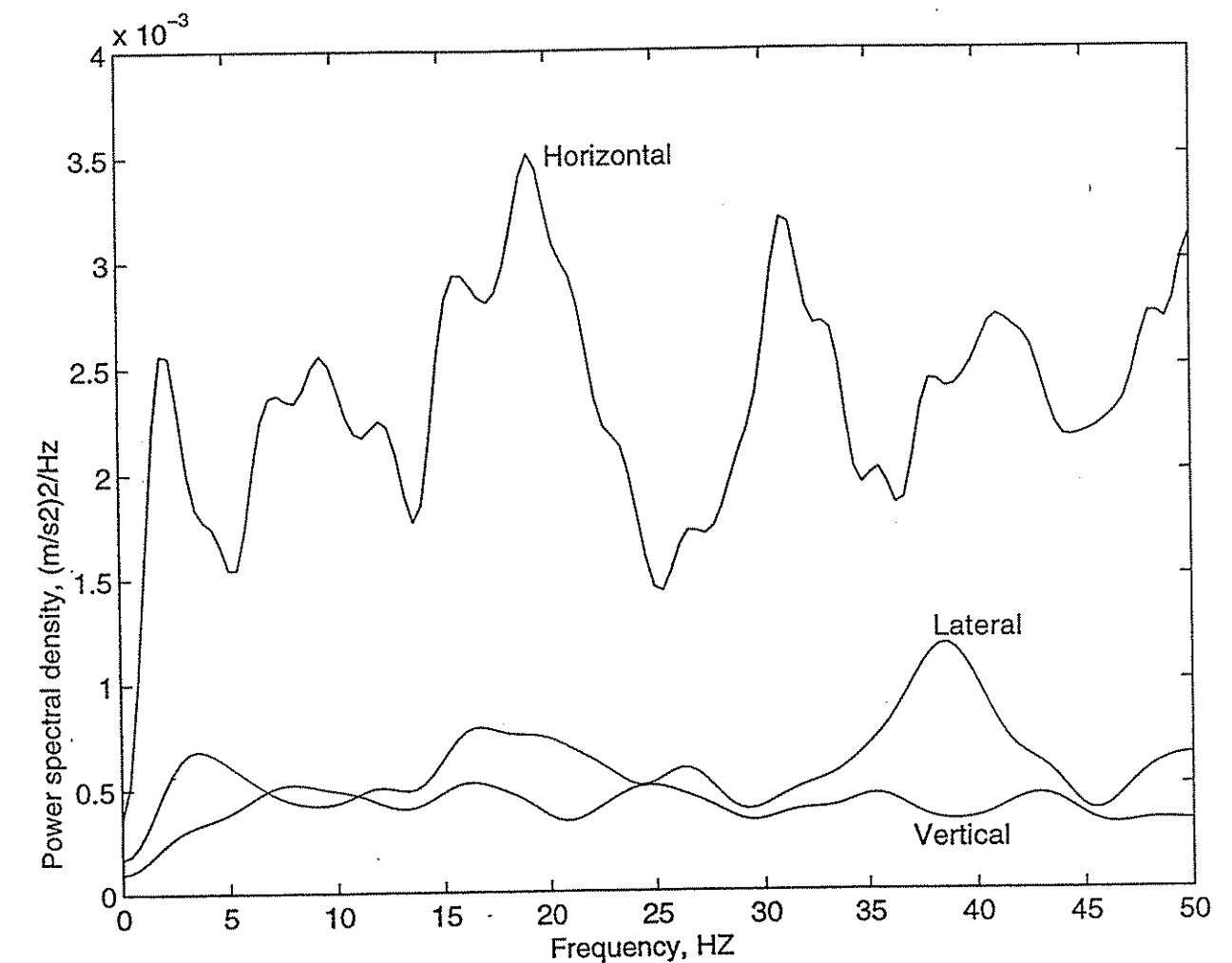


Fig. 15. Power spectral density of vibrations for varied speed of the vehicle

4.8. Effect of vibration on heart rate and pH

To study the effect of vibration on heart rate and pH, comparison was made between animals transported on relatively rough and curved roads and the ones transported on asphalted and fairly straight roads. From the frequency analysis, the amplitude of vibrations, when driving on a rough surfaced road, significantly increased (see Figures 13 and 14) when compared to the asphalted and straight highway. The r.m.s. acceleration for the rough and curved roads (70 kmph driving for both cases) increased by the factors 3.6, 4.5 and 6.6 for the vertical, horizontal and lateral vibration respectively.

The average final pH value of the meat of animals transported on a rough road is 5.85, while for the meat of animals transported on an asphalted road is 5.6. The corresponding average heart rate of animals transported on rough and asphalted road were 78 and 52 respectively. However, it should be noted that detailed investigations should be made to determine the effect of vibration on the ultimate pH value.

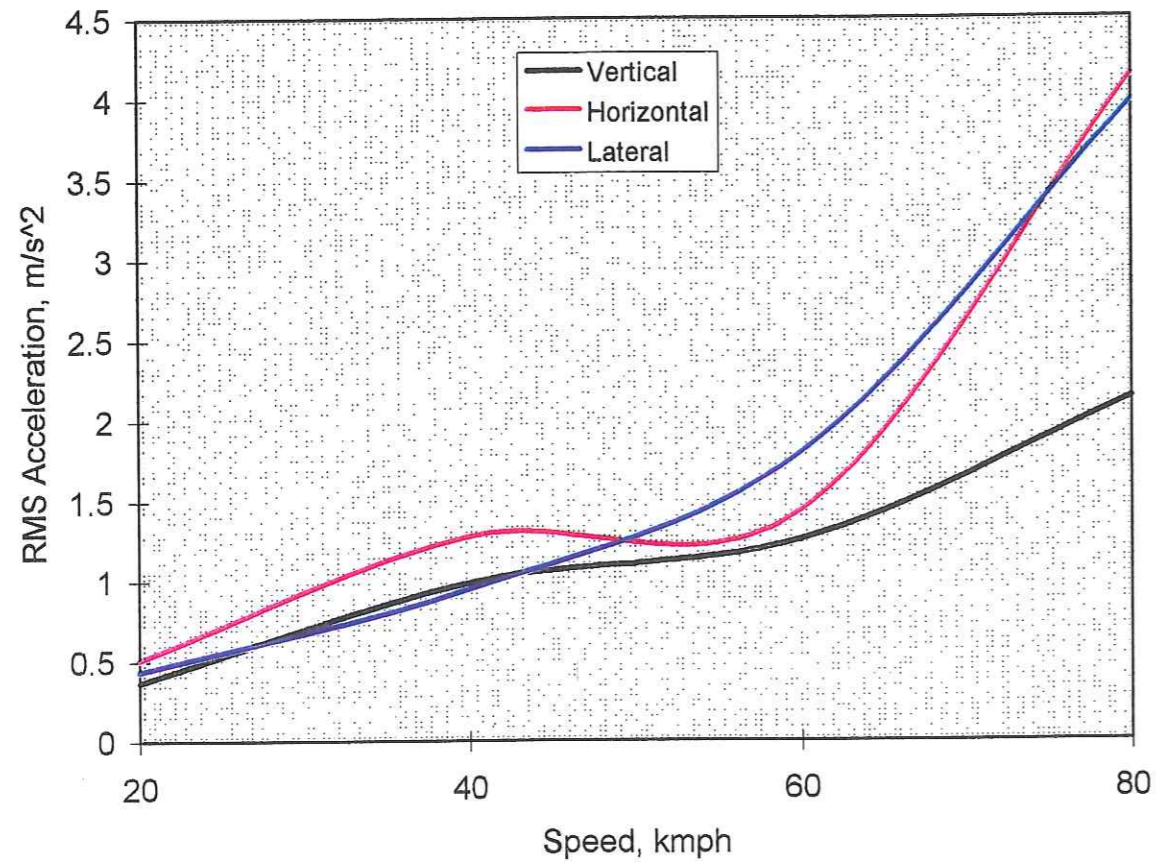


Fig. 16. Effect of speed on rms acceleration in vertical, lateral and horizontal directions

4.9. Transport route and air emissions

The locations of the farms may not lie in the same line, rather dispersed, and therefore transport route planning is very vital to be considered for all the three key parameters (animal welfare, meat quality and environment) and therefore it is necessary to optimize the transport route.

For the current project, nine routes were made, ranging from two hours and ten minutes to seven hours and ten minutes in time wise and 92 to 458 km in terms of distance. Comparisons were made between the actual transport routes the driver used and the computed and optimized routes. The route used by the driver was measured using GPS equipments and optimization was made using DPS software (DPS, 1995). Optimization and route planning reduced the transport distance by 8% to 14% and the emissions from the vehicle reduced by 10% to 18%. Figure 17 shows one of the optimized route when visiting eight farms. Optimization of this particular transport route decreased transport distance by about 10%.

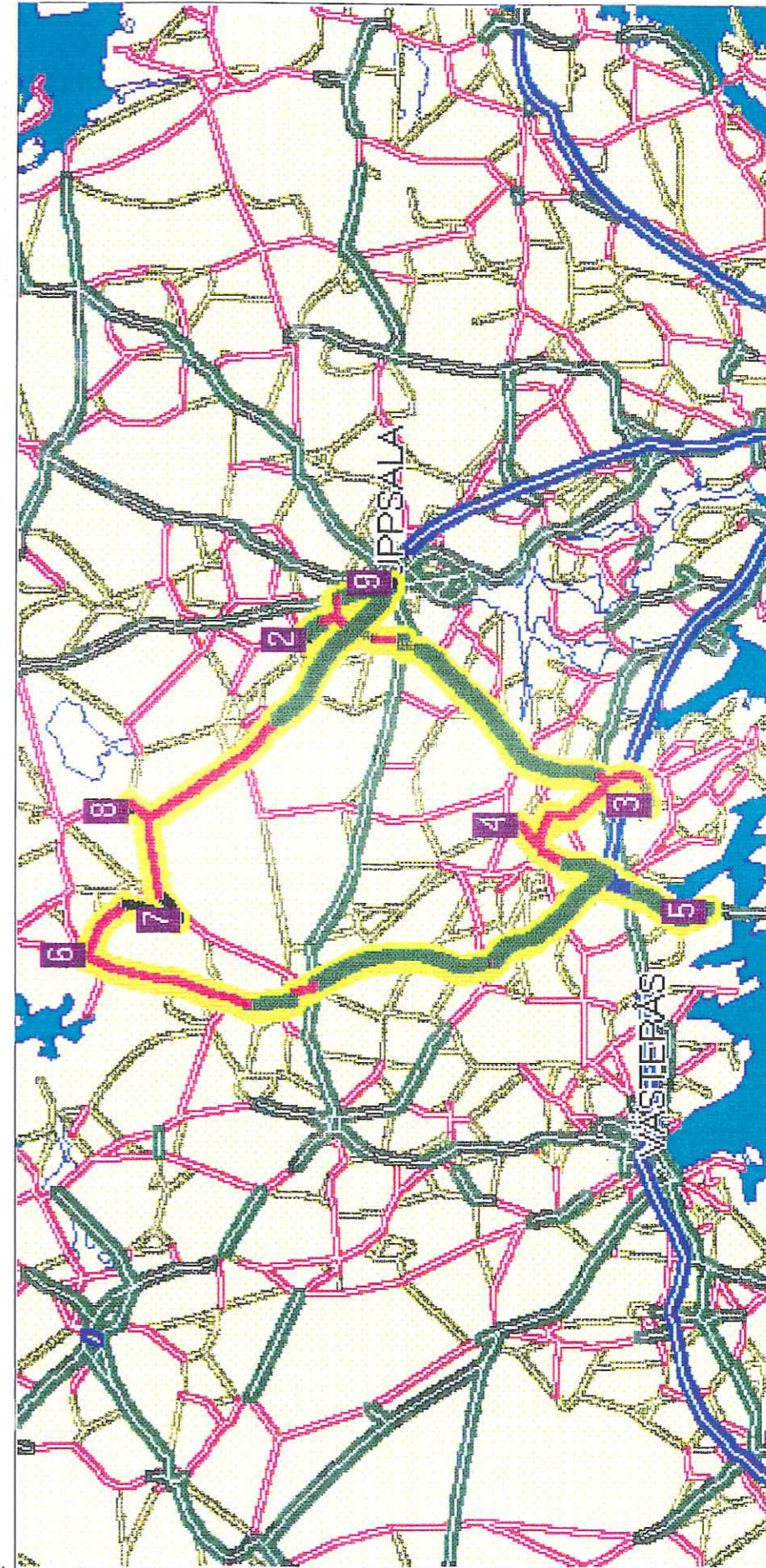


Fig. 17. Transport route when animals were collected from eight farm. The numbers represent visit addresses (farms)

The total transport work and the transport work within each stop, i.e., between farms, between farms and abattoir, and between abattoir and transport company were determined for each series of collection of animals from farms to abattoir and the result is given in Figure 18. The total transported distance was 421 km. Load utilization capacity of the vehicle was also determined in the course of the current work. Figure 16 depicts the load utilization level for the route when animals were collected from eight farms. The utilization level ranges from 0 to 100% with an average of 46% (Fig. 19).

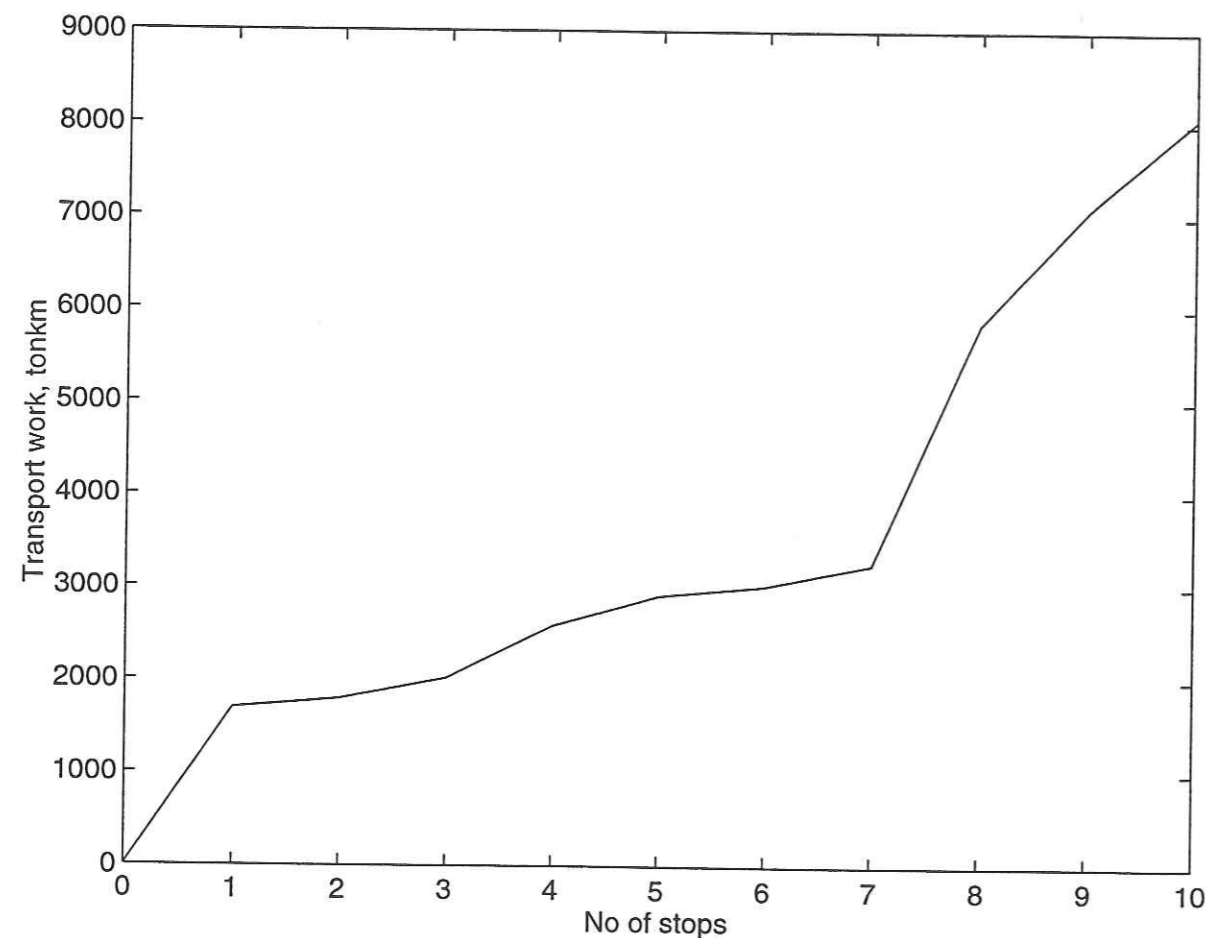


Fig. 18. Transport work in tonkm. The numbers on the horizontal axis represents sequential stops. The numbers 0 and 10 represent the terminal of the transport company, and 9 represents the abattoir. Other numbers denote farms (8 farms).

Air-emissions such as carbon dioxide, carbon monoxides, hydrocarbons, and oxides of nitrogen were determined for each route. The computed air emissions using the MODTRANS model (Gebresenbet and Oostra, 1997) for each route are reported in Table 4. Distance, load, speed, number of starts and slopes were considered for emission computation. For both route optimization and emission computation, the distance between the abattoir and transport company was not considered.

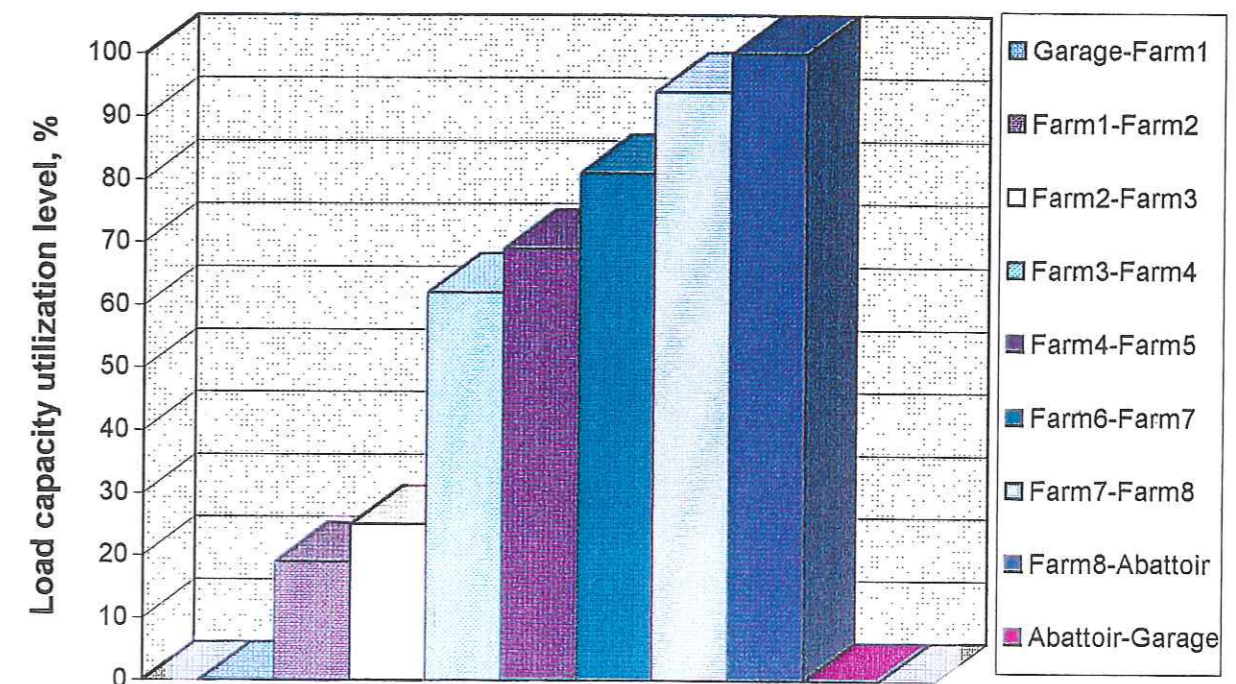


Fig. 19. Vehicle's loading capacity utilization level in percentage, during collection of animals from farms to the abattoir

4.10. Time distributions for various activities

The time distribution for various activities during transport for a scenario when all the transported animals were from the same farm was determined (Fig. 20). The activities include transport from the abattoir to the farm, preparation for loading, loading 16 animals, documentation, transport from the farm to the abattoir, waiting time at the abattoir and un-loading.

About 70% of the time is attributed to transport from abattoir to farm and farm to the abattoir. The driver usually washes the vehicle after every trip. The time taken to wash the truck within each trip interval was not taken into consideration in Figure 19. The washing time varies from 30 to 45 minutes. The waiting time (10% of the total) may be reduced if IT supported logistic system is developed.

Table 4. Route optimization and air emission from the vehicle. The values in the parenthesis are emissions computed for the optimized route

Route	Distance, km		Emission, kg			
	Before optimization	After optimization	NOx	CO	CO ₂	HC
1	105	94	6.1(5.4)	1.9(1.6)	361(323)	0.6(0.5)
2	84	75	4.6(4.1)	1.4(1.3)	275(245)	0.5(0.4)
3	89	80	5.7(5.1)	1.8(1.6)	337(303)	0.6(0.5)
4	152	135	7.9(7.0)	2.5(2.1)	470(418)	0.8(0.7)
5	112	103	6.8(6.2)	2.1(1.9)	405(372)	0.7(0.6)
6	173	157	11.5(10.4)	3.6(3.2)	684(621)	1.2(1.1)
7	279	240	18.6(16)	5.8(4.9)	1104(949)	1.9(1.6)
8	172	153	10(8.9)	3.1(2.7)	591(526)	1.1(0.9)
9	118	106	6.5(5.8)	2(1.8)	386(346)	0.7(0.6)

It should be emphasised that route planning is one of the major issues to consider. For example, the vehicle used for the present work drives for about 120 000 km/year consuming about 54 000 litre of diesel. Reduction of transport distance at least by 10% (i.e., 12 000 km) using route planning does not only reduce the fuel (i.e., by 5400 litre) thereby attenuate pressure on the environment, but also improves animal welfare and meat quality by reducing the time length animals are confined in a vehicle.

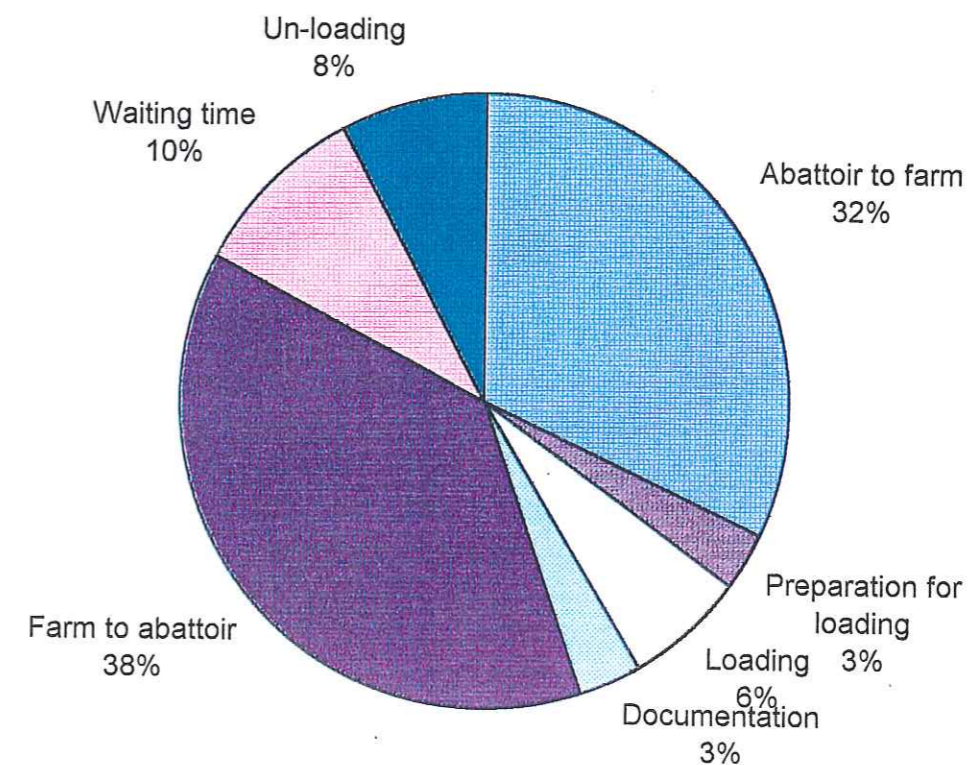


Fig. 20. Time distribution for various activities when all animals were transported from a single farm

5. Conclusion

The method and instrumentation developed to study the animal welfare, meat quality and environment performed sufficiently. The present work determined the most significant stress inducing factors on animals. Loading at the farms, performance of the vehicle, road conditions, social grouping or mixing with un-familiar animals, and un-loading procedure at the abattoir played significant role in stressing the animals.

About 20% of the animals had the ultimate pH-value more than 5.8, and classified as DFD meat. Driving on rough surfaced and curved roads and longer transport time attributed to higher pH values.

This study identified that the most common resonance frequencies of the vehicles vibration were 1.3, 3.6, 12 and 25 Hz. Speed of the vehicle and road conditions played role in the variations of resonance frequencies and magnitude of vibration. It was observed that an increase of amplitude of vibration by the factor of about 5 caused an increase of animals heart rate by 80%.

It has been found that route optimization reduced transport distance by 8% to 14%. This improves and promotes all the three key issues (i.e., animal welfare, meat quality and environment) raised in this paper and economy. Reduction of transport distance by 8 to 14% reduces air emissions from the vehicle by 10% to 18%.

Based on the results obtained, further comprehensive study is recommended to:

- a) make detailed investigation on the effect of transport length on meat quality of various categories of animals,
- b) carry out measurements on route system and perform optimization to promote economically effective and environmentally sustainable transport system of slaughter animals.

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References

- Baldock J M and Sily R M. Effect of handling and transportation on the heart rate and behaviour of sheep. *Applied animal behaviour science*. 28 (1990) 15-39
- Becker B A, Mayes H F, Hahn G L, and Nienaber J A. Effect of fasting and transportation on various physiological parameters and meat quality of slaughter hogs. *Journal of Animal Science*, 1989, 67: 334-341
- Bernhardsen T. Geographic information system. Viak IT and Norwegian Mapping Authority, 1992, Arendal, Norway
- Bradshaw R H; Parrott R F; Goode J A; Lloyd D M; Rodway R G and Broom D M. Behavioural and hormonal responses of pigs during transport: effect of mixing and duration of journey. *Animal-Science*. 1996, 62:3, 547-554
- British standards institution. Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock. BS 6841:1987
- Broom D.M. Welfare assessment and welfare problem areas during handling and transport. *Livestock handling and transport*, 1993 (edited by Grandin T)
- Carlsson S. Transport, blandning och motning av svin, en litteraturoversikt. Rapport 151, Institutionen för husdjurens utfodring och vård, SLU, 1985 (Department of animal nutrition and management, SLU)
- Clark D K., Friend T H., Dellmeier G. The Effect of orientation during trailer transport on heart rate, cortisol and balance in horses. *Applied animal behaviour science*, 38(1993) 179-189
- Cockram M S; Kent J E; Goddard P J; Waran N K; Mcgilp I M; Jackson R E; Muwanga G M. Effect of space allowance during transport on the behavioural and physiological responses of lambs during and after transport. *Animal-Science*. Jun 1996; 62 part 3 : 461-477.
- Cockram M S. Resting behaviour of cattle in a slaughter house lairage. *British-Veterinary-Journal*. 1991. 147: 2,109-119
- Distribution planning software Ltd, 1996. Route logix
- Duggan J.A., Randall J.M., Nicol C.J. Effect of whole-body vertical vibration upon tonic immobility reactions of the domestic fowl. Paper presented at meeting of human response to vibration, 1995, Silsoe research institute, UK
- Eldridge G A, Winfield C G, Cahill D J. Responses of cattle to different space allowances, pen size and road conditions during transport. *Australian journal of experimental agriculture (Australia)*, (1988). v. 28(2) p. 155-159
- Eldridge G A, Winfield C G. The behaviour and bruising of cattle during transport at different space allowances. *Australian journal of experimental agriculture*, 1988, 28: 6, 695-698

- Fabiansson, S., Erichsen I. Reuterswärd A L. & Malmfors G. The Incidence of Dark Cutting Beef in Sweden. *Meat Science* 10 (1984) 21-33.
- Fernandez X, Monin G, Culioli J, Legrand I, Quilinchí Y. Effect of duration of feed withdrawal and transportation time on muscle characteristics and quality in Friesian-Holstein calves. *Journal of animal sciences* 1996, 74: 7, 1576-1583
- Gebresenbet G., and Oostra H. Environmental Impact of Goods Transport with special emphasis on Agricultural and related products. Part I: MODTRANS, a simulation model for goods transport and environmental research. Rapport 219, SLU, Dept of Agric Engineering
- Gonyou H.W. Behavioural principles of animal handling and transport. *Livestock handling and transport*, 1993 (Edited by Grandin T)
- Grandin T. The Effect of stress on livestock and meat quality prior to and during slaughter. *International journal for the study of animal problems*; 1980, 1;5:313-337
- Griffin M J. Handbook of human vibration. Academic press limited, 1990, Sandiago, USA
- Gross W.B., Siegel P.B. General Principle of stress and welfare. *Livestock handling and transport*, 1993, edited by Grandin, T
- Guise H J, Penny H C. Factors influencing the welfare and carcass and meat quality of pigs. 2. Mixing unfamiliar pigs. *Animal production*, 1989, 49: 517-521
- Guise H J, Warriss P D. A note on the effect of stocking density and temperature on meat quality in pigs. *Animal-production*, 1989, 48: 2, 480-482
- Hails M R. Transport stress in animals: a review. *Animal regulation studies*; 1987, 4; 289-343
- Hails M R. Transport stress in animals: a review. *Animal regulation studies (Netherlands)*, 1978, v. 1(4) p. 289-343
- Honkavaara M, Kortensniemi P. Effect of long distance transport on cattle stress and meat quality. *Meat focus international*, 1994, 3: 10, 405-409
- Karlsson A., Lundström K. Meat quality in pigs reared in groups kept as a unit during the fattening period and slaughter. *British society of animal production*, 1992, 54, 421-426
- Kenny F J, Tarrant P V. The physiological and behavioural responses of crossbred Friesian steers to short haul transport by road. *Livestock production science (Netherlands)*, 1987, v. 17(1) p. 63-75
- Kenny F J, Tarrant P V. The reaction of young bulls to short-haul road transport. *Applied animal behaviour science*. 1987, 17: 3/4, 209-227
- Kenny F J, Tarrant P V. The behavioural responses of beef cattle to short haul road transport. (Abstract). *Applied animal behaviour science*. 1990, 26: 3, 292-293
- Kent J E, Ewbank R. Changes in the behaviour of cattle during and after road transportation. (Abstract). *Applied animal ethology (UK)*, 1983, v. 11(1) p. 85

- Knowles T G, Warriss P D, Brown S N, Kestin S C, Rhind S M, Edwards J E, Anil M H, Dolan S K. Long distance transport of lambs and the time needed for subsequent recovery. *Veterinary records*. 1993, v. 133(12) p. 286-293
- Lambooy E., Putten G.V. 1993. Transport of pigs. *Livestock handling and transport* (Edited by Grandin T)
- Lambooy E, Hel W-van der, Hulsegge B, Brandsma H A, Van der Hel W. Effect of environmental temperature and air velocity two days preslaughtering on heat production, weight loss and meat quality in non-fed pigs. *Energy metabolism in farm animals. Effect of housing, stress and distress* (edited by Verstegen M W A and Henken A M) 1987, 164-179
- Lambooy E. Road transport of pigs over a long distance: some aspects of behaviour, temperature and humidity during transport and some effect of the last two factors. *Animal-Production*. 1988, 46, 257-263
- Lapworth J W. Standards for loading and unloading facilities for cattle. *Applied animal behaviour science*. 28 (1990) 203-211
- Lundström K, Lundeheim N, Malmfors G, Malmfors B, Gahne B. Stresskänsligheten och köttkvalitet hos svine - inflytande av arv och miljö. *Konsulentavdelningens rapporter allmänt 24*, 1980, Uppsala.
- Lundström K, Malmfors B, Malmfors G. Meat quality in boars and gilts after immediate slaughter or lairage for two hours. *Swedish J. agric Res*, 1987, 17: 51-56
- Malmfors G, Lundström K, Fabiansson S. Influence of handling systems on meat quality of beef. 29th European Congress of Meat Research Workers, Parma, Salsomaggiore, Italy, 1983
- Malmfors G., Bredov B. The Problem of dark-cutting in veal. The paper presented at the congress of meat science and technology, Helsinki, Finland, 1988
- Mohan Raj A B; Moss, B W; McCaughey, W J; McLauchlan, W; Kilpatrick D J; McGaughey, S J. Behavioural response to mixing of bulls, vasectomised bulls and steers. *Applied-Animal-Behaviour-Science*. 1991, 31: 3-4 157-168
- Mojto J, Palanska O, Gallo J. Influence of transport on glycogen content in the muscle and technological quality of steer meat. *Polnohospodarstvo (Slovak Republic)*. 1994, v. 40(7) p. 377-382
- Möller B.M., and Borch. pH-värdets och glucosinnehållets betydelse för den mikrobiologiska hållbarheten samt avvikande lukt på nötkött. Rapport Y-92-90419, 1991, Köttforskningsinstitutet
- Möller B.M.; Forslid A. and Svensson, L. Kartläggning av hanteringsrutiner för storboskap. Rapport Y-101-92407, 1994, Köttforskningsinstitutet
- Polar Elecxtro Oy. Polar precision performance software, users manual, Kempele, Finland, 1996
- Randall J.M. Human subjective response to lorry vibration: Implications for farm animal transport. *J.agric.Engng Res.*(1992) 52,295-307.

- Randall J.M. Vibration on poultry transporters. *British poultry science* (1993) 34: 635-642
- Randall J M, Meehan A M. Vibration on a pig transporter. Paper presented at meeting of human response to vibration, Silsoe research institute, UK, 1993
- Randall J M. Livestock handling and transport. *Engineering advances and food. Proceedings of the 1938-1988 Jubilee conference of the Institute of Agricultural Engineers, Co-sponsored by the fellowship of the engineering, Robinson college, Cambridge, 12-15 September 1988* (edited by Cox S W R) 1988, 109-118, London, UK, Butterworths
- Rutter S M, Randall J M. Aversion of domestic fowl to whole-body vibratory motion. *Applied animal behaviour science*, 37 (1993) 69-73
- Scott G B. Effects of short-term whole body vibration on animals with particular reference to poultry. *World's poultry science journal*, 1994, vol 50
- Stephens D.B., Rader R.D. Effect of vibration, noise and restraint on heart rate, blood pressure and renal blood flow in the pig. *Journal of Royal society of medicine*, 1983, vol 76
- Stephens D B., and Perry G C. The effect of restraint, handling, simulated and real transport in the pig (with reference to and other species). *Applied animal behaviour sciences*, 28 (1990) 41-55
- Tarrant P V, Kenny F J, Harrington D. The effect of stocking density during 4 hours transport to slaughter on behaviour, blood constituents and carcass bruising in Friesian steers. *Meat science*, 1988, 24: 3, 209-222
- Tarrant P V. Transportation of cattle by road. *Applied animal behaviour science*. 28 (1990) 153-170
- Tarrant V., Grandin T. Cattle transport. *Livestock handling and transport*, 1993, Edited by Grandin T
- Trunkfield H R, Broom D M. The effect of the environment on calf responses to handling and transport. (Abstract). *Applied animal behaviour science*, 1990
- Trunkfield H R, Broom D M. 1990. The welfare of calves during handling and transport. *Applied animal behaviour science*. 28 (1990) 135-152
- Waran N K., Cuddeford D. Effect of loading and transport on the heart rate and behaviour of horses. *Applied animal behaviour science*, 43(1995) 71-81
- Warran N K; Cuddeford D. Effects of loading and transport on the heart rate and behaviour of horses. *Appl-anim-behav-sci*. Amsterdam;New York: Elsevier, 1984-. May 1995. v. 43 (2) p. 71-81
- Warris P D. The handling of cattle pre-slaughter and its effects on carcass and meat quality. *Applied animal behaviour science*. 28 (1990) 171-186
- Warriss P D. Ante-Mortem factors which influence carcass shrinkage and meat quality. 39th International Congress of Meat science and Technology. Calgary, Alberta, Canada, 1993

- Warriss P D, Brown S N, Knowles T G, Kestin S C, Edwards J E, Dolan S K, Phillips A J. Effect of cattle transport by road for up to 15 hours. *Veterinary records (UK)*. 1995, v. 136(13) p. 319-323
- Warriss P D. The effect of time and conditions of transport and lairage on pig meat quality. Evaluation and control of meat quality in pigs. A seminar in the CEC Agricultural research programme, held in Dublin, Ireland, 31-22 November 1985 (Edit by P V Tarrant) 1987, 245-264, Dordrecht, Netherlands; Martinus Nijhof publishers
- Wythes J R., Shorthose W R., Powell V H. Cattle handling at abattoir. I. The effect of of rest and resting conditions before slaughter and of electrical stimulation of carcasses on carcass weight and muscle properties. *Australian journal of agricultural research*, 1988, 39: 1, 87-95

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