# Animal Transport and Welfare with special emphasis on Transport Time and Vibration including Logistics Chain and Abattoir operations

Samuel Aradom
*Faculty of Natural Resources and Agricultural Sciences*
*Department of Energy and Technology*
*Uppsala*

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## Abstract

During transport animals are exposed to a number of stressors such as, separation from familiar and mixing with unfamiliar groups, vibration and transport time. Logistics chain of animals comprises collecting from farms, transport and unloading and slaughter chain operations. The current licentiate thesis deals with transport of pigs and cattle from farms to abattoirs including all logistics chain.

Two trucks with natural ventilation and air suspension systems were used for field experiments. Stress hormones such as cortisol, glucose, lactate and creatine kinease, ethological parameters, carcass pH value, temperature and relative humidity were measured to study effect of transport on pigs welfare. Vibration levels on chassi, floor and cattle were studied and the influence of speeds, road types and cattle standing orientations on vibration levels were investigated. Field measurements were also conducted to describe the potential effect of operations planning and route optimization on welfare and meat quality.

Highest pH24 value was (5.99±0.29) at 12 h summer transport time. Concentrations of cortisol was inversely proportional ($P<0.001$), lactate and creatine kinase ($P<0.002$) positively correlated where as glucose level ($P<0.01$) was highest at 8 h transport time. Lying, sitting and rooting correlated with transport time ($P<0.009$). On cattle, highest vibration was 2.27±0.33 m $s^{-2}$ on gravel road at 70 km $h^{-1}$. Vibrations in horizontal and lateral directions were lower on animals positioned perpendicular to driving direction. Uneven distributions of arrivals affected handling at the delivery gate. Unloading, including waiting and preparation, varied between 7 and 98, with an average of 23.7 minutes. Queues at washing occurred at 29% of deliveries, with waiting of up to 56 minutes. Potential savings for individual routes was up to 23%, consequently reducing negative impact on animal welfare, meat quality and environment. Based on climatic conditions, behaviours, stress hormones, and final carcases pH values, an increase from 4 to 8 h had higher effect than from 8 to 12 h transport time. To reduce vibration levels animal transporters more have to adapt vehicle’s speed to road and animal conditions. Time and distance of transport activity can be reduced through effective planning and route optimisation which also improves animals’ welfare and environmental impact.



Key words: transport time, animal welfare, animal behaviour, Creatine Kinease, vibration, route optimisation

*Author's address: Samuel Aradom*, SLU, Department of Energy and Technology,
P.O. Box 7032, 75007 Uppsala Sweden
*E-mail:* Samuel.Aradom@ slu.se

Dedication

To Rahel and Anna

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# List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. S. Aradom, G. Gebresenbet, F. S. Bulitta, E.Y.Bobobee and M. Adam. 2011. Effect of Transport Times on Welfare of Pigs. *Journal of Agricultural Science and Technology, publishing in progress.*

II. G. Gebresenbet, S. Aradom, F. S. Bulitta and E. Hjerpe. 2011. Vibration levels and frequencies on vehicle and animals during transport. *Biosysten Engineering, 110, 10-19.*

III. D. Ljungberg; G. Gebresenbet; S. Aradom. 2006. Logistics Chain of Animal Transport and Abattoir Operations. *Biosystems Engineering, doi:10.1016/j.biosystemseng.2006.11.003*

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The contribution of Samuel Aradom to the papers included in this thesis was as follows:

I Contribution to data collection, analysis evaluation, and manuscript writing.

II Contribution to data analysis, evaluation as well as manuscript writing.

III Contribution to most data collection and writing

# Abbreviations

| | |
|---|---|
| C | Cortisol |
| CF | Crest factor |
| CK | Creatine kinease |
| DFD | Dark firm and dry |
| eVDV | Estimated vibration dose value |
| FF | Forward orientation |
| Ft | Fighting |
| G | Glucose |
| L | Lactate |
| Ls | Loss of balance |
| Ly | Lying |
| PP | Perpendicular orientation |
| PSD | Power spectral density |
| PSE | Pale soft and exudative |
| Pt | Panting |
| Rc | Restlessness and change of position |
| r.m.s | Root mean square |
| Rt | Rooting |
| St | Sitting |
| THI | Thermal-humidity index |
| TR | Transport time |
| Vc | Vocalisation |
| VDV | Vibration dose value |

# 1. Introduction

## 1.1 Background

Animals are usually loaded and transported to slaughter house in groups from a single or several farms in one vehicle. Transport is an exceptionally stressful in the life of animals as it compromises their welfare (Knowles and Warriss, 2000). On the other angle, the current tendency is decreasing number of abattoirs and specialization on certain species, and this results in longer transport (both in terms of duration and distance) between point of production and the abattoir which may consequently affects animal welfare and meat quality.

Loading and unloading procedures involve separation of animals from familiar groups and original places and eventually move to new areas where they are subjected to restricted space, mixing with unfamiliar animals, sounds, vibrations and microclimatic environment etc. Furthermore level of handling methods and facilities of getting the animals on to, out of the truck and subsequent queuing and operations at the slaughter house have strong influence to ease or worsen the stressful situation. Some of the key elements in the design and performance of the animal transport vehicle are levels of thermal environment, ride comfort and floor type coupled with road conditions, speeds, length of transport time and driving performance impose stress and compromise the welfare of the farm animals.

Animal transport which involves among others, collecting from various farms, transport, queuing and unloading at abattoir, would be efficient when integrated with dynamic planning process that takes into account road conditions, climatic, traffic conditions, transport time and distance. Effective logistic system contributes to the reduction of poor welfare and emission as well.

Climatic conditions, loading density, duration of transport, cold draughts, heat stress, social stress, vibrations and noise all affect the condition of the pigs during transport (Lambooij et al., 1993). Therefore stressors that may be encountered during loading, transit and unloading can be a major threat to the welfare of cattle and pigs and other farm animals.

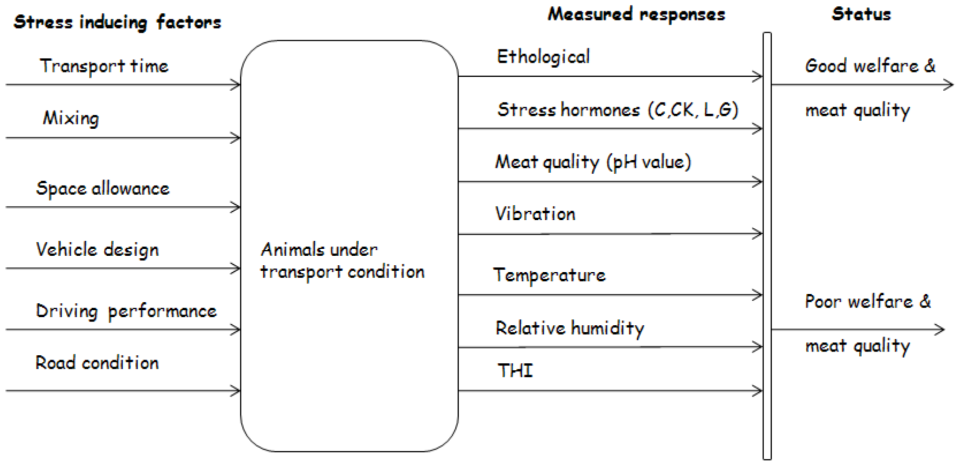



Figure 1: Stress inducing factors and stress responses during pigs and cattle transport.

Figure 1 illustrates animals’ condition under transport where stress inducing factors together with stress responses, welfare status and quality of end product are included.Transport (loading, transit and unloading) and interaction with unfamiliar animals, space allowance and vehicle design etc expose the animals to a number of stressors. These stressors are associated with behavioural, physiological changes including stress hormones (Broom, 2000). It can further be indicated in meat carcass in the form of pH level. Depending upon these and other responses animal welfare and meat quality can be evaluated.

During loading and unloading procedures and transport of farm animals, there are various indicators of stress. When the animals are under conditions of physical and psychological stress, it can be assessed by endocrine responses (Fazio et al., 2008). They can also exhibit behaviours which differ in pattern and frequency from the normal behaviours. When assessing animal welfare behavioural measures are among the preferred methods, because the way animals behave in respond to the new environment, gives a clear picture. Behavioral and physiological responses of an animal are indicators that the animal is having difficulty coping with handling or transport (Broom, 2007).

Stress before and during slaughter affects not only welfare of the animal, it can also cause adverse effects on the quality of meat in the form of pale, soft, exudative (PSE) and dark, firm dry (DFD). Meat quality below or above the normal pH value is generally undesirable to consumers.

During winter and summer transport, the animals may be exposed to a wide range of ambient temperature and relative humidity variations which resulted from seasonal, duration of loading and interaction of other factors. During transport, high temperature in a vehicle is a leading cause of death in pigs (Warris & Brown, 1994).

Unlike driver or passenger, animals are transported on vehicle's container. Road conditions, vehicle speed, driving style and standing orientation of the animals have significant influence on vibration levels. On a livestock transporter, the interfaces between the animals and the vehicle are not designed to reduce vibration and it is possible that animals are subjected to a higher vibration magnitude than the driver (Randall, 1992). Therefore welfare of animals which may vary from poor to good can be assessed by evaluating stress hormones, ethological parameters, carcasses pH level, temperature, relative humidity and vibration levels.

Transport (including loading and unloading) as well as the abattoir environment are the main stress inducing factor for the animals. Stress inducing factors can be minimized by improving animal transport logistic system and handling methods that include optimized abattoir activities etc (Gebresenbet, 2003). This results in good welfare and meat quality and less environmental impact and cost.

## 1.2 Literature review

## 1.2.1 Farm animals' transport

Effect of transport on farm animals in terms of welfare, economic loss and ethical concern and main parameters used to assess their welfare are considered in the literature review.

Transport and the associated handling may cause important losses to the livestock industry (Grandin, 2000), and social concern about the consequences of transport on animal welfare has gradually increased during recent decades, resulting in a legislation being past in the European Union (Council Regulation 1/2005/EC). Animal welfare' arose in society to express ethical concerns regarding the treatment of Animals (Duncan and Fraser 1997).

Animals are now defined as "sentient creatures" in European law and no longer just as agricultural products (Treaty of Amsterdam, 1997). That change reflects ethical public concern about the quality of life of the animals (European Food Safety Authority, 2004).

Transport is generally an exceptionally stressful episode in the life of animals and can compromises their welfare (Knowles and Warriss, 2000, Gebresenbet and Ericsson, 1998) and involves changes to their whole environment, or to many of its most important aspects (Appleby, 2008). The conditions under which animals are transported, rather than the act of transportation per se, may induce marked physiological stress which in turn, will compromise their welfare in transit (Malcom and Peter, 2008).

Stressors we expose animals to today in modern agriculture, such as long distance transport, are comparatively novel to the animals and as a result, we all too often over challenge the coping strategies animals have (Bench, 2007). In recent years the number of abattoirs in Sweden has been decreasing and the trend may continue in the future. This leads to increasing transport time and distance that may result in poor animal welfare and meat quality.

### 1.2.2 Effect of transport time on welfare of pigs

Several studies of transport (short and long) have mainly focused on its effect on mortality and live weight loss. Examining records collected through 10 years of pig slaughtering in the Czech Republic, Malena et al. (2007) found that mortality in fattened pigs increased with distance travelled (0.07% for journeys under 50 km and 0.32% for journeys over 300 km), however transport conditions were not specified. On the basis of data collected on 2.7 million pigs in the USA, Southerland et al., (2009) reported that the effect of journey time on the percentage of dead pigs increased for journeys lasting more than 30 minutes and decreased for journeys lasting between 5 and 11 h and the authors concluded that, mortality didn't increase in proportion of travelled time. Mortaltity is an evident indicator of poor welfare during transport (Warriss and Brown, 1994; Warriss, 1996a; Guàrdia *et al.*, 1996).

According to Lambooy, (1998) the range of weight loss in pigs, even in short-term transport is between 4-6%. Mota-Rojas et al., (2006) also reported similar findings, in a study carried out in the Mexican summer, that weight loss during transport for 8, l6 and 24 h was 2.7%, 4.3% and 6.8%, respectively. However, eight h of lairage allowed the pigs to regain some weight due to rehydration. Weight loss attributable to withdrawal of food and water during journeys represents an economic loss (Lambooy, 2007).

In considering the duration of transport, it has been reported that not only long transport time (8 h), but also short (1 h) journeys can affect the welfare of the animals with increased mortalities and pathological findings (Werner et al., 2007). But according to Averós et al., (2008) in respect to pigs' mortality average temperature is more important than the duration of the journey. Mota-Rojas et al., (2006) investigated the effects of mid-summer transport on preand post-slaughter performance and pork quality (in Mexico) and recommended optimal transport time. The authors concluded that transport should not take more than 16 h in order to improve carcass quality and animal welfare.

Nevertheless some researchers did not make emphasise journey time only but included loading and unloading durations and conditions as well. Ritter et al. (2006) reported that total time from loading to unloading was positively correlated with transport losses (dead and non-ambulatory pigs). The mixing of unfamiliar pigs at loading can increase both transport deaths and carcass damage (Gosalvez et al., 2006). Bradshaw *et al*. (1996b) also reported increased cortisol levels, on 1.5 and 8 h journey time and led them to the conclusion that this rise, initially a response to loading, was maintained as a response to transport.

Various studies have reported that rate of dehydration is greatly accelerated by road transportation (Warriss, *et al*., 1983; Becker *et al*., 1989). Increasing transport duration increased drinking post-transport and blood haematocrit, indicative of rising levels of dehydration and thirst (Lewis and McGlone, 2007). Weight loss attributable to withdrawal of food and water during journeys represents an economic loss (Lambooy, 2007). Among other factors, it is known that the duration of the journey has a negative influence on welfare and meat quality (Bradshaw et al., 1996; Faberge et al., 2002; Perez et al., 2002; Mota-Rojas et al., 2006) although, if proper handling is provided before and throughout transportation, stress levels may be reduced even during long journeys (Brown et al., 1999a).

It should be important to detect conditions under which loading, transport and unloading of animals are performed. Suppose they enter the vehicle in stressed mode, when there is inadequate ventilation and space allowance and mixing of unfamiliar animals and the driving style causes discomfort and increased vibration intensity. In that case the animals in transit are already in stressed situation regardless duration of transport. The condition under which animals are transported, rather that the act of transportation per se, may induce marked physiological stress which in turn, will compromise their welfare in transit (Malcom and Peter, 2008).

### 1.2.3 Welfare assessment during transport

The main parameters to be considered when assessing animal welfare are: stress hormones, behavioural alteration, meat pH value, temperature, relative humidity and vibration.

## Stress hormones

Behavioural and physiological changes related to the stress response can yield very useful information (Fraser and Broom, 1990; Warriss *et al.*, 1998b).When an animal encounters adverse condition, it leads to change of hormones and measurements of these hormones can be used to evaluate welfare of the animal. Plasma measures, such as creatine kinase (CK), lactate dehydrogenase (LDH) and cortisol, are reported to change in response to stressors (Fabrega et al., 2002, Helmreich et al., 2006 and Jarvis et al., 2006 ), and these changes are often used to reflect stress coping characteristics and metabolic status of the animal. Knowles and Warriss (2000), identified main causes and physiological indicators of stresses during transport like, fear/arousal increases cortisol concentration, physical exertion elevates creatine kinease and lactate levels and motion sickness raises vasopressin concentration in the blood. Animals in a single farm may vary in their response to the same or similar potential stressor. According to Moberg, (1985) individual animals of the same species may handle threatening situation differently. Studies to determine the amount of stress of farm animals during transport often have highly variable results and are more difficult to interpret from an animal welfare standpoint (Grandin, 1977). Schrader and Todt (1998) reported that in pigs, peripheral endocrine stress responses are accompanied by changing rates of specific types of vocalizations. Hormones responses to handling and transport can vary considerably from one animal to another; therefore it should be combined with behavioural studies as indicator of animals' welfare.

## Behavioural changes

To measure the severity of stress during transport, behavioural indicators have been usually used. Measurement of animal welfare is not always easy and several welfare indicators should be used (Grandin, 2000). Behaviour has a number of major advantages in welfare studies. According to Dawkins (2004), it is non-invasive and in many cases non-intrusive. The most obvious indicators that an animal is having difficulty coping with handling and transport are changes in behaviour, which show that some aspect of the situation is aversive (Broom, 2000). Several studies have shown that pigs significantly increase their non-vocal and vocal behavioural activities in stressful situations, such as in social separation (Fraser 1974, 1975; von Bore11 & Ladewig 1992; Hessing et al. 1994). Pigs try to stay in contact with one another in stressful conditions and this can be seen in huddling behaviour during transport because in such situation they are calmed by the presence of their pen mates (Lambooij et al., 1993).

While it may intuitively appear that fearful animals may be easy to move, animals that are fearful of humans are likely to be the most difficult to handle (Hemsworth, 2007). An important behavioral measure of welfare when animals are transported is the amount of fighting which they show; the recording of such behaviour should include the occurrence of threats as well as the contact behaviours which might cause injury (Broom, 2000). Behavioral changes can be quantified using comparisons of responses (stopping when they encounter shadows, bright areas, dark areas, etc.) Grandin (1981a, 198b,1997, 1998). Grandin (1990) reported that during loading, transport and unloading, injuries and bruising occur by forceful contacts in passageways, compartments and containers, and because of fighting among animals. Warriss et al. (1998) reported skin-blemish damage in 63% of slaughter pigs (10% had “moderate” damage) and concluded that fighting between mixed groups of unfamiliar animals was the probable cause.

## Meat pH level

Welfare measurement is not always easy and several welfare indicators need to be used in order to draw an accurate conclusion (Bench, 2007). Stress before slaughter can have impact on both welfare and end quality of meat. Acute stressor imposed on pigs immediately prior to slaughter will increase muscle temperature, increase lactic acid concentration, and increase rate of muscle pH decline post-slaughter (Moss, 1984), which in turn can lead to pale, soft and exudative (PSE) pork. Pérez *et al.* (2002) reported that pigs transported for only 15 minutes showed significantly lower pH values in various muscle groups compared with animals transported for 3 h. Valenta and Provaznik (1996) also found higher incidence of PSE meat after short transport (< 40 km) although the pigs rested for 1-4 h before slaughter.

On the other extreme, prolonged stress prior to slaughter can lead to depleted muscle glycogen concentrations, low muscle lactic acid concentration post-slaughter, high ultimate pH, and dark, firm, dry (DFD) pork (Tarrant, 1989). Imposition of long-term transport stress before slaughter lead to increased DFD meat in pigs (McPhee and Trout 1995). Both PSE and DFD meat cuase substantial economic losses especially dark cutting (Frase and Broom, 1997). The likelihood of DFD and PSE meat is related to pre-slaughter stress (Honkavaara, 1989; Gregory, 2007). Fàbrega et al. (2002) found a relationship between a high percentage of dark, firm, and dry (DFD) meat and a lower welfare index. Thus, animal welfare and meat quality are inseparable. However, there is no consistent association between indices of stress and meat quality parameters (Warriss *et al.*, 1998b; Bradshaw *et al.*, 1999).

## Temperature and relative humidity

Microclimatic environment in a naturally ventilated vehicle has important implication for welfare of farm animals. When ambient temperature changes animals use both physiological and behavioural mechanisms either to increase heat production or to promote heat loss and maintain homeothermic (National Research Council Committee, 2006). When lying on a well bedded floor Lower Critical Temperature (LCT) for pigs are reduced by 3 to 5 °C (Bruce, 1981). Some of the main impacts of hot and cold weather conditions and length of transport on pigs are summarized below.

There are distinct seasonal differences in pig transit death rates with a clear peak in the summer months, when the conditions are hot and wet (van Logtestijn et al., 1982; Abbott et al., 1995). Investigation on mortality rate was carried out during transport on 10.3 million pigs. The rate increased from 0.07% for outside temperatures lower than 5°C to 0.11% for temperatures higher than 15°C. It also increased with the length of the journey from 0.084% for journeys shorter than 75km to 0.12% for journeys longer than 150km (Colleu and Chevillon, 1999). Honkavaara (1989) investigated pigs' mortality during summer and winter conditions in Finland. It was low during heavy frost (-30 to –20 °C), increased considerably in cold weather (-3 to 0 $^{0}$C) and was highest in warm weather (16 to 26 $^{0}$C). During transport of animals on lorries the main criterion is to prevent the Upper Crtical Temperature (UCT) from being exceeded. An air temperature of 32°C could be selected as a maximum design value. The use of water spray on pigs will act to increase evaporative cooling (Lambooij and Engel, 1991). The number of pigs which showed panting increased when the temperatures of transport vehicle exceeded 25 $^{0}$C (Sällvik *et al.,* 2004). A natural ventilation system is entirely dependent upon the movement of a vehicle. When the vehicle stops for loading and other activities sudden rise of temperature can occur. The case may be critical during hot seasons. Sällvik et al. (2004) reported that the temperature inside a standing vehicle with natural ventilation at loading increased by 0.15 $^{0}$C/min. Small rises from the normal pig body temperature of 39–42 degrees proved fatal (Lambooij et al., 1993), so adequate ventilation on transport vehicles and the weather of the day must be taken into consideration. High temperatures and high humidity prevent the animals releasing their heat. Low temperatures and high air humidity may enhance heat dissipation and the animals suffer from cold, but the worst conditions for heat loss occur at high temperatures and high humidity (EC,1999). The Upper Critical Temperature (UCT) for finishing pigs may be as low as 23°C, depending on factors such as body size, feeding, and hydration status, and conditions of transport such as load density (Lamboy, 2000; Randall, 1993; Schrama, 1996). No signs of thermal stress were observed in slaughter pigs on transport vehicles at air temperatures between 10 and 25 $^{0}$C (with an optimum at 18 to 20 $^{0}$C) in France (Chevillon *et al.*, 2002). Thermal stress is recognised as one of the major reasons of reduced welfare and health of the animals which can decrease end product quality and may even cause death ( Dantzer, 1982). Thus to prevent poor welfare, fluctuations of temperature and relative humidity should be within the optimum comfort range of the animals in transit.

## Vibration

During transport of farm animals, vibration is one of the potential stressors. Vibration on animals has received little attention despite the recognition that in human and animals it may induce fear, nausea, distress and fatigue because of the distribution of the oscillatory motions and forces within the body (Randall et al., 1993). Vibration is characterized by its direction (horizontal, vertical and lateral) and amount frequency and acceleration (Tooley, 2009). Vibration, which depends on vehicle design, and the jolting, shocks, and sudden impacts caused by road conditions and driving skill, may compromise animal welfare (Peeters et al. 2008). A large, fixed-body truck with air suspension provides a very smooth ride, classified as not uncomfortable to a little uncomfortable (Randall et al., 1996).

Several vibration studies were carried out on farm animals like pigs and poultry. On a vehicle used for poultry transport, Scott (1994) reported that, the fundamental frequency is 1-2 Hz and with secondary peak occurring at 10 Hz, the value coincides with the resonance frequency of poultry viscera. Detailed measurements by Randall et al., (1996) found that resonance frequency of broilers were around 15 Hz when sitting and 4 Hz when standing. Warriss et al., (1997) reported broiler chickens subjected to narrow band vibration (2, 5 and 10 Hz) at 2 $ms^{-2}$ root mean square, had decreased pH ultimate in both pectoralis superficialis (PS) and biceps femoris (BF) muscles. Furthermore as the frequency increased there appeared to be greater depletion of glycogen in the liver.

Calves subjected to vibrations at a frequency of 2 Hz become more stressed compared with vibrations of 12 Hz (Van de Water et al., 2003 a, b). Wikner et al., (2003) found that most of the animals change position in perpendicular orientation to the vehicle's motion. They further reported that vibration values are higher on gravel than paved road surface for unloaded cattle transport vehicle. Pigs with a body weight 20 and 25 kg were vibrated in a vertical direction for 2, 4, 8 and 18 Hz in combination with root mean square 1 or 3 $ms^{-2}$. Comparing with 2 and 4 Hz spent time lying was 10 times shorter at 8 Hz and 18 times shorter at 18 Hz (Perremans et al., 2001). The proportion of pigs standing or lying was associated with an increase or decrease in acceleration (Peeters et al., 2008). In comparison to pigs and birds, it seems that studies dealing with cattle have received little attention. From welfare aspects, there is lack of cattle vibration data which limits determining the vibration levels as well as comfort ranges.

### 1.2.3 Logistics chain and abattoir operations

In a pre-slaughter logistics chain and its effect on lambs meat quality, the animals were transported from the original farm to temporary stayed residence. Depending upon their weight they stay 7, 28 or reloaded immediately for slaughter. It was concluded that stay time had significant effect ($P<0.001$) on meat texture (Miranda-de la Lama et al., 2009). A small scale local abattoir that depends on regional supply of animals would have direct impact on animals' welfare, meat quality and environment. Reductions in transport time and distance during collecting animals from farms and delivery to abattoir were 42 % and 37% respectively (Gebresenbet et al., 2011).

A prototype web-based geographic information system has been developed and installed on long distance animal transport vehicle. The equipment records vehicle geographic coordinates, date, time and internal temperature of the vehicle etc. It enables immediate visualization on map of the current position of animal being transported and also makes it possible to monitor the status of animal welfare (Ippoliti et al., 2007).

Use of quality information is a key element in effective logistics planning and decision making in pork supply chains. Despite the recent developments logistics processes are still subject to a number of inefficiencies, like poor material usage, operational inefficiencies or low perceived product quality at final customers (Rijpkema, 2011).

Time window of animals to be transported from farms to abattoir for slaughter is variable depending upon category of the animal. Therefore time window of specific species should be taken into account during planning. Furthermore abattoir's activities require effective planning to reduce queuing and lairage time at delivery gates.

# 2. Objectives

The main objective of the thesis work was to study the welfare of farm animals during transport from farm to abattoir and the specific objectives were to:

- investigate the effect of transport times of up to 12 h on the welfare of pigs;
- study vibration and frequency levels on typical cattle transport vehicle and animal; and
- describe logistics chain of animal transport and abattoir operations, and demonstrate the potential effect of operations planning and route optimization on animal welfare, meat quality, and environment.

# 3. Materials and Methods

Transport was usually conducted between farms and abattoirs and the studies were performed on farms and abattoirs. The studies consisted of field measurements, interviews, observations and activities documentation. Commercial livestock transporter vehicles were used for field experiments.

## 3.1 Vehicles and sensors

Typical pigs' (Volvo FH13) and cattle (Volvo FM 12 4x2) transporter vehicles owned and operated by commercial companies were used for the experiments. They had air suspension system and equipped with adjustable loading ramps. The floors were covered with sawdust over a rubber mat (approximately 20 mm thick). When animals were in transit, provision of ventilation occurred through apertures positioned along the length of the vehicles body. The opening could be adjusted manually depending on the weather conditions.

The Pigs' transporter vehicle was tri-axled, semi-trailer with 3 decks and its overall dimensions were 2.45 m x 13.6 m. The observation pen was located on the third floor and having 2.68 m (length) and 2.45 m (width) dimensions. Temperature and relative humidity sensor and video camera were fitted in this pen.

Cattle transporter vehicle had a single deck, and was fitted with two pens separated by a steel gate. The front pen (cab end) measured 2.41m x 2.67 m and the back pen 2.41m x 2.56 m. Each pen accommodated four cows. The vehicle was fitted with sensors Acc1, Acc2 and Acc3 to measure vibrations on chassis, floor and animal, respectively. The sensors Acc1and Acc2 were connected to a computer by cable and measurements were made at a sampling frequency of 1000 Hz for three channels (vertical, horizontal and lateral vibrations), i.e. 333 Hz per channel.

A Cargolog FAT 90V2 battery-powered electronic logger system was used to measure temperature and relative humidity (Cargolog manual, 2009). The system consisted primarily of two parts: portable, battery-operated recording and communication units. A PC interface unit was used to communicate with the recording unit, download parameters, initiate sampling sequences and download the collected data after recording periods. Measurement of temperature and relative humidity were performed simultaneously and continuously throughout transport time.

Fixed and hand held cameras (Sony DCR-HC47E) were also used to monitor animals' behaviour and Rolab vibration sensor unit described earlier (Gebresenbet et al., 2005) was used to measure vibration levels on the animals. It was a tri-axial accelerometer. The sensor measures acceleration in a range of frequency from 0 to 500 Hz with a full-scale range of ±10g.

Vehicle speed, geographical location (latitude and longitude) of animal collection points (farms), delivery point (abattoir), slope and undulation of roads and route were recorded during each journey using an antenna placed on the cab roof and connected to a MAGELLAN 315 GPS signal receiver by cable. The information was then transferred to a computer in the cab by cable from the GPS unit.

## 3.3 Animals, parameters and analysis

## 3.2.1 Transport time

In total, 2753 pigs were transported from various farms to the abattoir and out of these 216 were transported in the observation box and behavioural study was made on them. However, blood samples were collected from 90 pigs for field experiment, and blood samples were also collected for control purposes from 20 pigs that were not in transit. The mean space allowance was 0.55 $m^2$ $pig^{-1}$. The standard space allowance according to EU regulation of 2005 is 0.51 $m^2$ $pig^{-1}$ weighing up to 100 kg. The age of the pigs was six months and their average weight was 100 kg. Eighteen measurements were performed during winter and summer seasons for 4, 8, and 12 h of transport time with three replications for each transport time.

Blood sample were taken at the farm before and after transport and subsequent stunning at the abattoir for determination concentration levels of cortisol, creatine kinase, glucose and lactate. Control blood samples were also collected from pigs using the same technique. Blood samples were taken from jugular vein. Collected blood samples were centrifuged for at least 10 min at 2000 rpm at room temperature. Separated cells and plasma were removed using Pasteur pipettes, placed in 1.5 mL micro tubes and stored at -20 °C until analysis.

Meat samples were taken from the longissimus dorsi (LD). The carcases were chilled for 24 h at +4°C. During that time, temperature and pH decrease were measured at 5, 12, 18 and 24 h post-mortem.

Pigs behaviours were continuously observed and documented at farms (during blood sampling and loading), transport (in the vehicle) and on unloading at the abattoir by visual observation, portable and fixed video cameras. To evaluate behavioural alterations in response to handling and transport activities, based on literature and experiences definitions were given to the most common observed behaviours. In the study duration of events were included in a more accurate approach to demonstrate the severity of each factor that caused behavioural alterations. For determination of frequency, occurrence of events and total number of animals in the observation box were considered. Occurrence and duration of events were determined from video recordings and documentations of observation made during the field work. Therefore, the final quantified behaviour was expressed as the product of frequency of events and duration of events.

$$Frequency = \frac{A}{B} \tag{1}$$

$$Behaviour = Frequency \times t \tag{2}$$

Where:

A: Occurrence of behaviour

B: Total number of pigs in the observation box

t: Duration of events in minutes

Environmental variables considered during pigs’ transport were temperature and relative humidity. During winter and summer transport, the animals were exposed to a wide range of ambient temperature and relative humidity variations. Temperature and relative humidity inside container of the vehicle were measured simultaneously and continuously throughout transport time. Thermal-humidity index (THI) was later calculated. THI is a single value representing the combined effects of air temperature and humidity associated with the level of thermal stress. It was calculated to determine the level of thermal stress using the equation:

$$THI = 0.8\, t_{ab} + RH\,(t_{ab}-14.4) + 46.4 \tag{3}$$

Where $t_{ab}$ is dry bulb air temperature ($^{o}C$) and RH is relative humidity in decimal form.

Statistical data analysis has been made separately for blood parameters, behavioural pH and air quality with SAS 9.2 statistical package PC-based program. Multivariate analysis was also done using General Linear Model (GLM), Multivariate analysis of variance (MANOVA) and clustering (dendrogram).

### 3.2.2 Vibration measurement

Dairy cows from 20 farms (95 in total, 62 Swedish Red and White and 33 Holstein) were used in field experiments. Five cows were used for each trip. Vibration levels on the animals were measured in three directions using tri-axial accelerometers. Each sensor measures acceleration with a full-scale range of ±10 m $s^{-2}$ and can measure both dynamic and static acceleration in the frequency interval 0-500 Hz. The logger containing sensors was mounted with tape on a girth belt around each animal's chest. On each trip, measurements were made on five animals simultaneously. Each measurement was triggered manually via the cab computer and data could be transferred wirelessly between logger and computer by a radio signal system. The vibration equipment picked up signals from a transmitter in the stock crate via an antenna mounted centrally on the ceiling and measured automatically for 20-second periods with the same sampling frequency as the Acc1 and Acc2 sensors. During the field experiment, only some data were transferred to the computer. Most were saved in the logger itself and transferred to the computer at the end of each experiment. The design of the field experiment was four speeds (30, 50, 70 and 90 km $h^{-1}$); three road types (gravel/poor tarmac (*RT1g/RT1*), good tarmac (*RT2*) and motorway (*RT3*)); and two standing orientations (facing forward (FF) and perpendicular (PP) to the driving direction). Two repetitions were performed for each combination.

Vibration data were frequency weighted, and prior to data analysis, the raw data were filtered using a second order Butterworth filter with low and high frequency cut-off of 0.1 and 250 Hz, respectively. The parameters, root mean square *(r.m.s)*, crest factor (*CF*), vibration dose value (*VDV*), estimated vibration dose value (*eVDV*), transmissibility, 8 h vibration exposure and power spectrum density (*PSD*) were then evaluated. All analyses were performed using Matlab software (version R2009b). Statistical data analysis has also been conducted with SAS software, using GLM and ANOVA procedures.

## 3.3 Logistics chain of animal transport and abattoir operations

The main activities considered were collecting from various farms, loading, transporting and unloading of slaughter animals at the abattoir, and operations in the slaughter chain from lairage box to cooling room for carcasses. Logistic activities were identified as part of: (i) vehicle activity chain and (ii) animal activity chain. Detailed data collection was made at four levels: (a) truck-driver interviews; (b) transport route on-board activity registration; (c) delivery gate activity registration (including vehicle and animal activities); and (d) slaughter chain activity registration.

### Truck-driver interviews

Investigation based on interviews was carried out with drivers of cattle transport on the general patterns of animal transport routes and drivers' perceptions of strengths and weaknesses in the logistics chain. The information collected was used to serve as a reference to the observations and measurements.

### Transport route on-board activity registration

Time used for loading, driving, and unloading was registered. Time, geographic positions (latitude and longitude) and all activities performed were documented using hand held GPS receiver. Furthermore, geographic positions were registered during driving (reference points) to enable replication of the route choice in-between collection points. The accuracy of position, stated by the producer, was 15 m root mean square (RMS). Signals from the GPS satellites have a good general coverage in the area where the study was made. Transport route on-board activity registration was made during 22 animal transport routes, (cattle, pigs and sheep).

## Delivery gate activity registration

The observed activities at the abattoir were classified as vehicle and animal activities. Vehicle activities were based on observation of the vehicle or the load (all animals on the vehicle) seen as one entity, while animal activities were based on observations of individual animals. Detailed registrations of abattoir operations were made during 30 h of observation. The activities included vehicle arrival and queuing, unloading, and washing; and animals' movement and lairage. There were 60 farm animals' deliveries that consisted of 31 cattle , 18 pigs and 1 sheep.

## Slaughter chain activity registration

Activities in the slaughter chain were mapped out in detailed form, based on information collected through interviews and direct observations. Interviews and limited observations during 20 h were used for the description of activities involved in the slaughter chain, from stunning to cooling room.

The analysis of results concentrated on identification of bottlenecks in the chain. The registered data were analysed to determine the impact of frequency of arrival of animal on-board vehicles and duration of activities, queues, capacity utilization, and other system constraints. RouteLogiX Professional v2.15 s (DPS, 1996) route optimisation software was used for the analysis of routes. The route choice between call points, as well as the visit order for call points, could be optimised with respect to time, distance or cost. In this study, optimisations were made with respect to time, which was assumed to imply that excessive use of narrow roads would be avoided in the proposed solutions. Time and distance were calculated for each registered route and compared to driving time duration. Twenty-two routes were recorded, all with start and stop at the abattoir. However two of the routes involved only one collection point each and were not included in route analysis. There was also one invalid GPS registration and it was unusable for route choice analysis. Therefore in total, 19 routes were analysed.

# 4. Results

## 4.1 Effect of Transport Times on Welfare of Pigs (Paper I)

During winter measurements, the values of pH0 and ultimate pH ranged from 6.5 to 5.5, where as summer pH values varied between 6.29 and 5.99. pH24 values during summer correlated with transport time ($r^2 = 0.69$) as illustrated in Fig. 2.

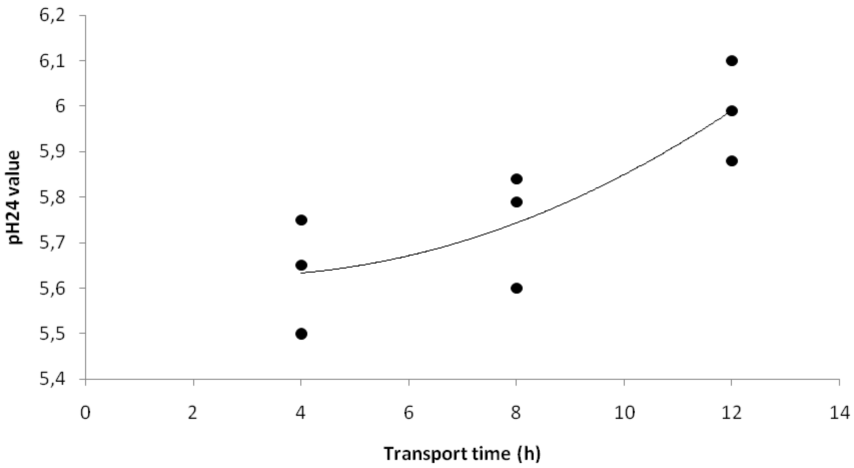



Figure. 2 Effect of transport time on pH24 value in pig carcases during summer, with correlation coefficient, $r^2 = 0.69$.

The concentration of cortisol was significant (P<0.001) and elevated during short transport and the rate of elevation decreased with an increase of transport time. The rate of elevation (58.2-25.3 nmol $L^{-1}$, winter; 59.2-31.8 nmol $L^{-1}$, summer) was generally inversely proportional to transport time for the range of transport time used for this study.

The effect of transport time on concentration level of blood glucose was significant (P<0.01). Glucose concentration increased from short to medium duration and decreased thereafter. Therefore it was highest at 8 and lowest at 12 h transport time for winter and summer experiments. During 8 h transport time, the maximum concentration noted was 20.46 mmol $L^{-1}$, and that was 3 fold more than the reference value.

Concentration levels of lactate (winter) in the blood increased (4.7 – 6.2 mmol $L^{-1}$) with an increase in transport time and positively correlated ($r^2$=1) (P < 0.002).

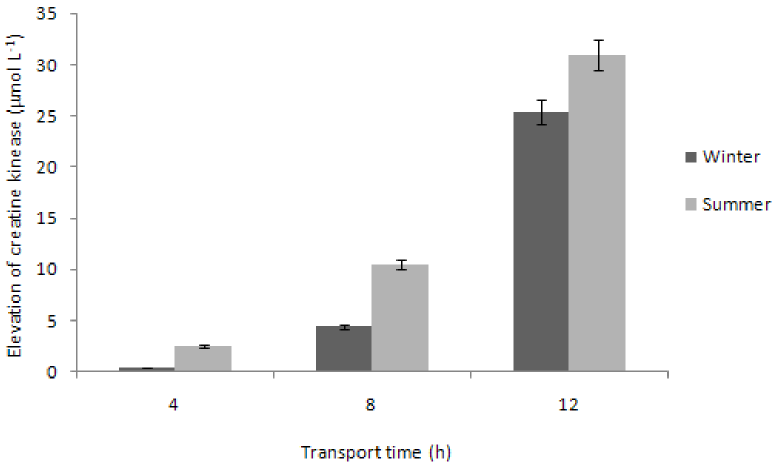



Figure 3. Creatine kinase concentration level for winter and summer increased exponentially with transport time, $r^2$ = 0.99.

The elevation in concentration levels of creatine kinase ranged from 0.4 to 25.4 (winter) and 2.5 - 31 (summer) µmol $L^{-1}$ and thus positively correlated with transport time (P<0.002). The relationship between concentration level and transport time was exponential ($r^2$ = 0.99) for both seasons. The rate of increase from 4 to 8 h was lower than from 8 to 12 h transport time (Figure 3). For summer season and 12 h transport time, the maximum value after transport was 154 µmol $L^{-1}$, and exceeded the reference value of 129 µmol $L^{-1}$.

Lying, sitting, rooting, vocalization, restless and change of position, smelling, panting, loss of balance and fighting were significant and positively correlated with transport time (P<0.009). About 50% of pigs were lying about two h after the vehicle started moving. About 80% of pigs were lying after 6 h transport time, and the behaviour remained similar until 12 h (Figure 4).

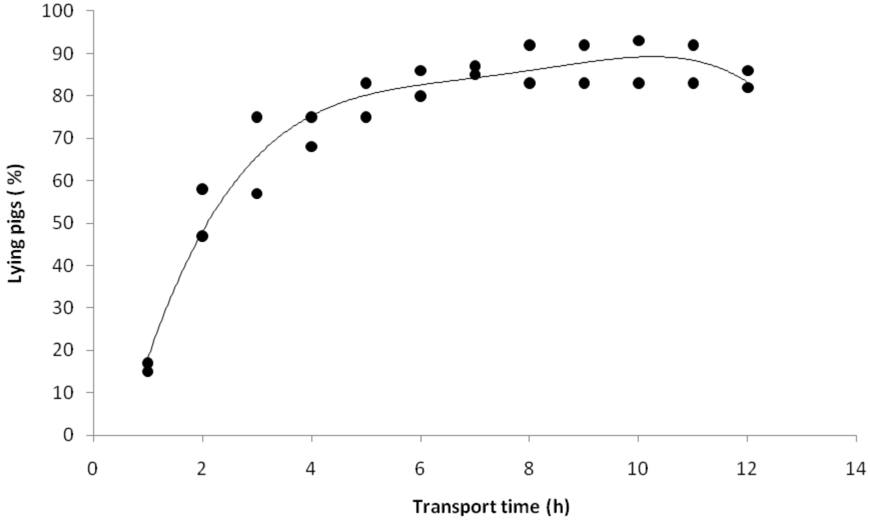



Figure 4. Proportion of pigs lying in percentage depending on transport time, described with 4th order polynomial function, with correlation coefficient, $r^2 = 0.95$.

Unlike other behaviours which occurred at both events, reversal appeared only when loading took place. Even though loading and unloading were independent of transport time, the severity or stress levels were higher during loading.

During field measurements the lowest temperature (-2 $^{o}$C) was recorded in February and the highest (28 $^{o}$C) in July and the highest value occurred during loading event. In all measurements, whether temperature was rising or falling, relative humidity constantly increased during transport. Relative humidity reached its maximum value both during winter and summer experiments. When initial relative humidity levels was below 60% , during loading, there was comparatively slow relative humidity growth and thereafter it decreased rather faster, as the vehicle started moving (compared to higher initial humidity). Thermo-humidity index (THI) mean values of both seasons and for the three transport times (4, 8 and 12 h) were below the threshold value of 74 and the maximum mean value was 65.92. However during summer season the maximum THI was 79.2 which was in the danger zone. These occurred when loadings took place.

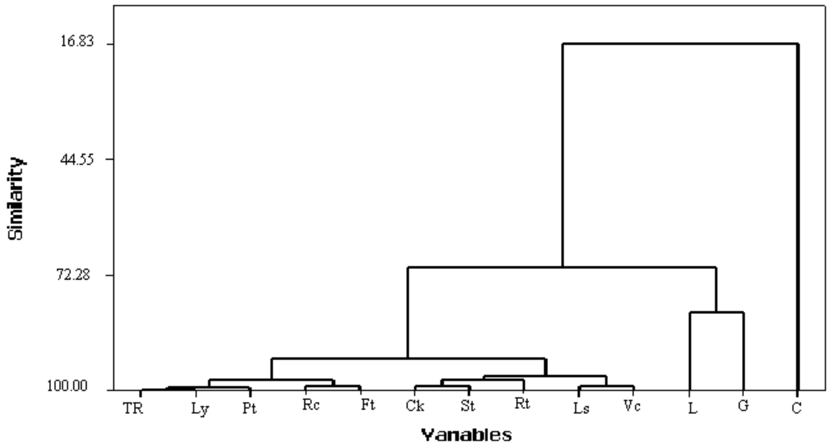



Figure 5. Dendrogram of transport time and stress related behaviour and blood hormones

Variables TR-Ly, Ls-Vc, Ck-St, Rc-Ft and L-G formed pair wise clusters at nearly same level of similarities, 98- 100% ,with the exception of L-G. Sub-clusters mainly composed of behaviours (Pt, Rt) formed main cluster at 91.33% level of similarity as illustrated in Figure 5. Two major clusters which consisted of behaviour and blood parameters (Lactate and Glucose) merged at 72.28% similarity. When C is sequentially added to the main clusters, it occurred at a wider level (16. 83%), showing weak level of similarity. In the clusters, behaviours like lying, panting, restlessness and change of position and fighting are located nearest to transport time the most similar variables, where as farthest neighbour are the less similar.

## 4.2 Vibration levels and frequencies on vehicle and animals during transport (Paper II)

Acceleration along horizontal axis, a histogram corresponding to the Gaussian normal distribution curve was obtained with the mean value of $\mu = 0.51$ m s$^{-2}$ and standard deviation of ±0.19. Chassis vertical vibration increased in an exponential form ($a = 0.6035e^{0.0167v}$) when the speed increased gradually from 14-92 km h$^{-1}$. The highest vibration values measured on animals were 2.23±0.27 and 2.27±0.33 m s$^{-2}$ in the driving direction on gravel roads for driving speeds of 50 and 70 km h$^{-1}$, respectively (Table 1).

Standing orientation, for all roads and speeds, animals facing in the driving direction (FF) were generally exposed to higher horizontal vibration levels than animals facing perpendicular (PP) to the driving direction (Table 1). The same was true for lateral vibration levels, but not for vertical vibrations. Vibration Dose value (*VDV)*, estimated Vibration Dose Value ( *eVDV)* and root mean square (*r.m.s)* were higher on cattle than on the floor along the horizontal and lateral directions, but lower in the vertical direction. Transmitted acceleration

Table 1 - Mean acceleration levels, with standard deviation, on animals at different speeds, road types, standing forward (FF) and perpendicular (PP) to the driving direction

| Speed Km $h^{-1}$ | Road type | Standing orientation | Vertical m $s^{-2}$ | Horizontal m $s^{-2}$ | Lateral m $s^{-2}$ |
|---|---|---|---|---|---|
| 30 | *RT1* | PP | 0.56±0.01 | 0.85±0.12 | 0.38±0.04 |
| | | FF | - | - | - |
| 50 | *RT1g* | PP | 0.3±0.28 | 2.23±0.27 | 0.81±0.5 |
| | | FF | - | - | - |
| | *RT1* | PP | 0.52±0.26 | 1.08±0.69 | 0.26±0.15 |
| | | FF | - | - | - |
| | *RT2* | PP | 0.48±0.21 | 1.09±0.31 | 0.42±0.66 |
| | | FF | 0.49±0.5 | 1.54±0.45 | 0.55±0.42 |
| 70 | *RT1g* | PP | 0.35±0.92 | 2.27±0.33 | 0.8±0.45 |
| | | FF | - | - | - |
| | *RT1* | PP | 0.31±0.29 | 0.87±0.09 | 0.35±0.23 |
| | | FF | - | - | - |
| | *RT2* | PP | 0.49±0.58 | 1.08±0.55 | 0.38±0.16 |
| | | FF | 0.47±0.42 | 1.51±0.5 | 0.5±0.3 |
| | *RT3* | PP | 0.34±0.44 | 1.1±0.36 | 0.48±0.25 |
| | | FF | 0.33±0.4 | 1.54±0.49 | 0.53±0.45 |
| 90 | *RT2* | PP | 0.36±0.24 | 1.6±0.24 | 0.54±0.1 |
| | | FF | 0.36±0.34 | 1.45±0.58 | 0.58±0.58 |
| | *RT3* | PP | 0.32±0.19 | 1.16±0.32 | 0.51±0.26 |
| | | FF | 0.30±0.4 | 1.52±0.53 | 0.54±0.46 |

Table 2 - Cattle and floor vibration exposure during 8 h transport time (tarmac road, *TR2*)

| | Verical | | Horizontal | | Lateral | |
|---|---|---|---|---|---|---|
| | *r.m.s* $m\ s^{-2}$ | Exposure $m\ s^{-2}$ | *r.m.s* $m\ s^{-2}$ | Exposure $m\ s^{-2}$ | *r.m.s* $m\ s^{-2}$ | Exposure $m\ s^{-2}$ |
| Animal | 0.63±0.13 | 0.61±0.12 | 0.68±0.25 | 0.92±0.35 | 0.75±0.16 | 1±0.21 |
| Floor | 0.67±0.03 | 0.64±0.03 | 0.63±0.03 | 0.85±0.04 | 0.51±0.03 | 0.7±0.04 |

*VDV* and *r.m.s* from chassis to crate's floor were 55-73%, 39-56% and 48-66%, respectively. However, transfer of vibration from floor to animal was 100-158%. The vibration exposure values in the vertical, horizontal and lateral axes for cattle (Table 2) were 0.61±0.12, 0.92±0.35 and 1±0.21 m $s^{-2}$, respectively. All these are above the EU exposure action value for humans (0.5 m $s^{-2}$) and that in the lateral direction was close to the daily exposure limit (1.15 m $s^{-2}$). In the vertical direction, three main resonance frequencies were identified for the vertical direct, at 1.3, 5.1, and 12.6 Hz, and a secondary peak at about 23 Hz.

## 4.3 Logistics Chain of Animal Transport and Abattoir Operations (Paper III)

### *Vehicle activity chain*

Seasonal and short-term variations in supply and demand, created challenges to the planning of cattle transport operations. Cattle were delivered to slaughter for three reasons; slaughter weight reached for meat production, milking cows removed from production due to lameness and other diseases, or the entire production at a farm closed down.

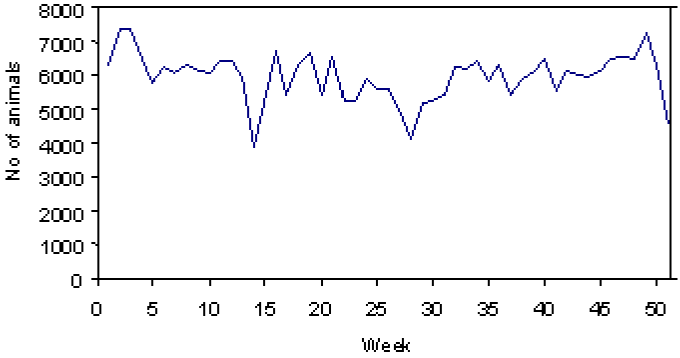


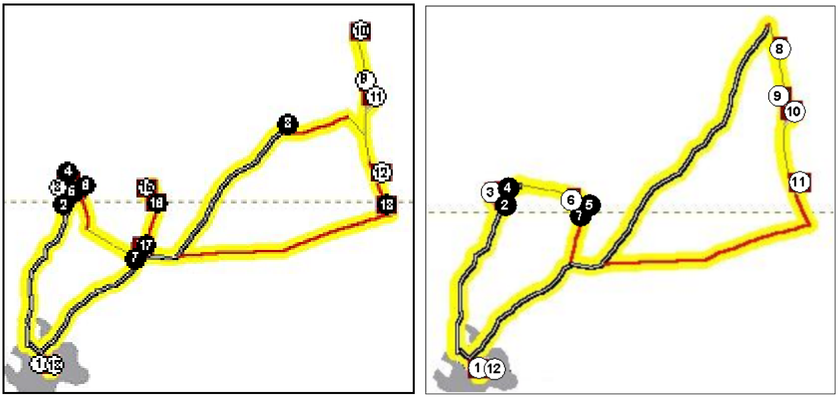

Figure 6. Number of animals delivered weekly to Swedish Meats, Uppsala, during one year

The planning of deliveries under unpredictable conditions (inherent from especially the latter two of the above mentioned reasons) required some flexibility in animal transport and abattoir. The seasonal variations in cattle transport to Swedish Meats abattoir in Uppsala is indicated in Figure 6. The long term planning of operations was based on a pre-registration of delivery information received from producers.

The drivers estimated that loading at farms required on average 26 min per farm, with variations from 10 to 180 min. According to observations of 22 routes involving in total 90 collection stops at farms, the effective average loading time was 12.7 min. while the time required for preparations before and after loading was 6.5 min. Drivers' estimations of unloading time at the abattoir, when there were no queues, varied between 15–60 min, with an average of 27 min. Queues were said to occur at around 20%, or less, of the deliveries at the abattoir, and likewise before vehicle wash. Waiting times in case of queues were estimated by the drivers to be on average 24 min (max 80 min) before unloading and 30 min (max 80 min) before washing. Important factors behind the build-up of queues were vehicles arrivals before or after the assigned/expected time, and the stable capacity was limited to 350 pigs. After unloading, washing the vehicle took 60 min (varied between 30 and 150).

## Route optimization

Departure time varied from 8:22 to 12:00 h, and arrival time at the abattoir from 11:30 to 19:02 h. The differences between registered and calculated driving times for the 19 routes were approximately normal distributed around an average of 6.4% of recorded driving time. Although for most routes the optimised route was identical with the drivers' route choice, the analysis revealed potential savings for individual routes of up to 23%. One of the routes with potential savings is displayed in Figure 7.




(a) (b)

Fig. 7 (a) registered route no.14 (3 h 14 min driving time, 174 km distance), (b) optimised route (2 h 45 min, 153 km); call points (departure, collections and delivery); reference points

## Animal activity chain

After unloading, the cattle were moved either directly to the stunning point, or to lairage boxes. The reasons for keeping cattle in lairage were that the slaughter capacity was temporarily filled, or the cattle arrived after slaughter chain was closed for the day. In the lairage box for 55 observed cases, animals' waiting time was on average 43 min. For 15 of the same animals (27%), lairage time exceeded 1 h (maximum was 2.2 h). During a technical breakdown in the slaughter chain, for 17 observed animals the lairage times increased to on average of 3.8 h; minimum 2.2 h and maximum 6.5 h.

# 5. Discussion

Ultimate pH value was higher during summer (5.99) than winter (5.5) thus season in the form of thermal effect has strong influence on the ultimate pH value.
Cortisol concentration was significantly ($p<0.001$) elevated during short transport thus inversely proportional to transport time. Creatine kinase concentration was positively correlated with transport time ($P<0.01$; $r^2 = 0.99$). The continuous increase in creatine kinase with an increase in transport time noted in this study indicated increasing muscular fatigue, which could be attributed to restlessness and loss of balance behaviours of pigs during transport.

Glucose concentration increased from 4 to 8 h and thereafter decreased slightly ($P<0.01$). Lactate concentrations (winter) positively correlated ($p < 0.002$; $r^2 =1$) with transport time. Lying, sitting, rooting, vocalization, panting, fighting, loss of balance, and smelling were behaviours that scored high values and were positively correlated with transport time ($p<0.009$). Behaviours like rooting, reversal and vocalization showed that the severity of stress was higher during loading than unloading. In cluster, behaviours like lying, panting, restlessness and change of position together with blood parameters showed stronger level of similarity to transport time (TR) to describe stress.
The pH24 value during summer season for 12 h transport time exceeded 5.8, and the elevation of pH24 might be attributable to climatic conditions in the vehicle, where the peak thermo-humidity index (THI) value was also noted to be 79.24 during the 12 h transport time, i.e. above the threshold value of 74. Most of the values of stress hormones and behaviour increased slightly or remained steady state between 8 and 12 h. During summer loading caused thermal stress. Inadequate ventilation after washing was the main cause for high initial relative humidity.

The highest vibration values measured on animals were ($2.23\pm0.27$ and $2.27\pm0.33$ m s$^{-2}$) in the driving direction on gravel roads at speeds of 50 and 70 km h$^{-1}$, respectively. Animals experienced lower horizontal vibrations when facing perpendicular to the driving direction than when facing forwards. They were also exposed to lower levels of lateral acceleration in the perpendicular orientation. Along horizontal and lateral directions level of vibration was higher on cattle than on the floor. Transmitted acceleration, Vibration Dose Value (VDV) and root mean square (r.m.s) from floor to animal were 100-158%, 101-154% and 95-143% respectively. Therefore vibration transmitted from floor to animal is higher than from chassi to floor. The vibration exposure values in vertical ($0.61\pm0.12$ m $s^{-2}$), horizontal ($0.92\pm0.35$ m $s^{-2}$) and lateral ($1\pm0.21$ m $s^{-2}$) directions for an 8 h transport period exceeded the EU daily exposure action (0.5 m $s^{-2}$) but were below the daily exposure limit (1.15 m $s^{-2}$).

Queues at the delivery gate and vehicle wash, was one of the major problems, as reported by the drivers. Cattle were frequently kept for more than 1 h, and occasionally more than 2 h, in the lairage box. Keeping cattle in the lairage box functioned as buffer storage to maintain continuous supply to utilize capacity in the slaughter chain. However, this capacity utilisation may compromise animal welfare. Furthermore, not even when the lairage box was full, the capacity of slaughter chain operations could be fully utilised, since the stunning and bleeding operations were bottlenecks in the chain. Uneven distribution of arrival of vehicles at the abattoir created queues at the delivery gate and vehicle wash, which had negative impact on animal welfare. Waiting times and queues at the delivery gate could be reduced through improved delivery planning.

The current study showed that transport time and distance could be reduced through the use of route optimisation, saving up to 23% in time for individual routes with overall average of 3.9% both in time and distance. Reduced length and time of transport have positive impact on welfare of animals, quality of meat and also in reducing emission and cost. Through effective planning of animal transport logistics chain, abattoir operations and route optimizing there is a potential to improve not only animal welfare and meat quality but also emission and cost. Collecting animals from several farms to single abattoir can be planned through route optimization.

# 6. Conclusion

The overall conclusion from the study of pigs' welfare and transport time, based on climatic conditions, animal behaviour, stress hormones, and final pH values in carcases, that an increase in transport time from short to medium h had a higher effect than an increase from medium to long h on the welfare and subsequent meat quality.

Ethological parameters, stress hormones, carcass pH value and environmental conditions in a combined form could provide a better picture of animals' welfare status during transport. In naturally ventilated pigs' transport vehicle, there should be adequate ventilation after washing and before the start of loading animals. Duration of loading and resting time should be kept to minimum to control the rapid heat build up in the container of the vehicle. Animal transport vehicles have to be equipped with necessary devices to monitor inside environment and behaviour of the animals.
Perpendicular to driving direction is recommended orientation in terms of vibration level. Drivers of animal transport vehicles have to adapt vehicles' speed to road type and animal conditions so as to minimise vibration related stress and subsequent injury.

Through effective planning and route optimisation, collecting animals from several farms to a single abattoir would be achieved in a shorter distance and time, moreover arrival at delivery gate and vehicle washing can be evenly distributed thus eliminating idle time. When transport time and distance are reduced, it is beneficial not only in terms of cost and environment but also in animal welfare aspects.

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