Nederlandse Voedsel- en Warenautoriteit
Ministerie van Landbouw, Natuur en Voedselkwaliteit

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To the Inspector-General of the Netherlands Food and Consumer Product Safety Authority

Advice from the Director of the Office for Risk Assessment and Research (BuRO)

Advice regarding the use of sensor technology to promote animal welfare in slaughterhouses

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Background

The Netherlands Food and Consumer Product Safety Authority (NVWA) is responsible for supervising compliance with statutory requirements in slaughterhouses, in respect of the public values of animal welfare and food safety. At present, the around 90 medium-sized to large slaughterhouses in the Netherlands voluntarily cooperate with camera-based monitoring by the NVWA, showing processes with live animals. The camera footage from slaughterhouses can be reviewed by the NVWA on-site and can be used to support enforcement. The footage itself is the property of the slaughterhouse. Partly in response to the NVWA's 'camera-based monitoring for animal welfare in slaughterhouses' evaluation, the Minister of Agriculture, Nature and Food Quality (LNV) is preparing legislation regarding camera-based monitoring. Part of those preparations is a bill that makes camera-based monitoring a statutory obligation and makes it possible to impose rules regarding 'smart' camera-based monitoring. By means of pilots at slaughterhouses, in collaboration with the NVWA, an investigation will be conducted into how smart camera-based monitoring can contribute to supervising compliance with the standards for animal welfare and the role required of government in safeguarding the quality and reliability of these systems[1,2]. Commercial parties are already actively developing applications for sensor technology for measuring animal welfare at slaughterhouses, and applications are already in use at slaughterhouses in the Netherlands.

The smart use of sensor technology[3], such as camera-based monitoring, may make a contribution to improving the protection of the public value of animal welfare. In the Risk Assessment Letter 2021, the Office for Risk Assessment & Research (BuRO) of the NVWA emphasises that the main motivations for supporting the use of cameras and camera-based supervision could and should not only be improved efficiency, but above all more effective and

[1] Parliamentary Paper, House of Representatives, session 2020–2021, 28 286, no. 12171, Government Letter; Outstanding motions and undertakings in response to two-minute debate on the progress of improving the slaughterhouse system
[2] Letter to Parliament, 22-04-2022, Letter to Parliament outcomes of study into slaughtering speed and progress of improvement in the slaughtering system, DGA-DAD / 22027151
[3] Sensor technology is a form of technology where a sensor observes the environment and gathers information. A sensor is an artificial model of a sensory organ. Using artificial intelligence (AI), the information gathered can be analysed. In this advisory report, sensor technology refers to measurements conducted with sensors in a general sense. Where there is reference to a 'smart' application combined with AI, this refers to sensor technology combined with AI.

better quality supervision. The possibilities of camera-based monitoring and sensor technology in combination with artificial intelligence (AI) need to be investigated. This does not refer to the selective viewing of camera footage in order to identify wrongdoings, but mainly to the development of new techniques and methods based on modern camera and sensor technology in combination with AI that can supplement, innovate and improve the supervision of animal welfare. From this viewpoint, the Inspector-General (IG) of the NVWA has requested BuRO to issue advice on the introduction and optimum application of camera-based monitoring at slaughterhouses.

Approach

BuRO has taken up the IG's request in a broader sense and will be carrying out a multiyear programme focusing on the theme of Sensor Data & AI in the coming years. As part as this programme, in this advice, BuRO has conducted an initial review of the possibilities of sensor technology for animal welfare in slaughterhouses. This review not only investigated cameras but also the use of other sensors and the possibilities for using AI, as well as taking a broader view than merely investigating the possibilities for use in enforcement by the NVWA. Other forms of sensor technology include microphones, speedometers and thermographic cameras.

The following question was formulated by BuRO for this survey:
What are the opportunities in the short and medium term for the use of sensor technology at slaughterhouses for the public value of animal welfare?

To answer this question, the following issues were studied, in stages:

1. Which animal-based measures are available to assess animal welfare at the slaughterhouse and with which types of sensor technology can these animal-based measures be monitored?
2. What initiatives related to sensor technology combined with AI and the measuring of animal welfare have already been applied in research and in practice at slaughterhouses?
3. What are the opportunities and limitations of sensor technology in slaughterhouses?
4. What are the prerequisites for the application of sensor technology for use by the NVWA?

To answer these questions, BuRO conducted a scientific literature study into the application of sensor technology for measuring animal-based measures in relation to animal welfare (see Appendix 1 for the search strategy). In addition, BuRO made use of publications it has previously published on animal welfare as well as internal NVWA documents such as working instructions and factsheets. Finally, a draft version was shared with a number of external researchers with experience in the field of AI and animal welfare for a fact check, posing the question whether the overview of existing systems was complete.

The answer to this question can be found in the substantiating arguments contained in this advice.

Scope

This advisory report deals with the use of sensor technology combined with AI at slaughterhouses to assess animal welfare. In the current review, no attention is focused on the use of sensor technology in relation to food safety. This aspect will be considered at a later stage. Animal health has been included as part of animal welfare. Commercial applications of

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sensor technology at the slaughterhouse have to date generally been focused on food safety and product quality, and far less on animal welfare. This advice discusses measurements and assessments conducted at the slaughterhouse, but relates to animal welfare both at the slaughterhouse itself and in the earlier life phases of the animal such as at the farm. In this study, we restricted our scope to the most commonly slaughtered animal species, i.e. chickens, pigs and cattle.

Findings

Animal-based measures

- The effect of a situation can best be measured on the animal itself by means of animal-based welfare measures (hereinafter 'animal-based measures').
- These animal-based measures can be assessed at various points in the slaughterhouse, during unloading of the animals, in the waiting pens, when driving, stunning and killing the animal, and post mortem (PM) on the carcass.
- The measurable animal-based measures at the slaughterhouse can be divided into three categories:
  - Still images, such as footpad lesions or bruises
  - Moving images, e.g. animal movement, such as in relation to lameness, falling or movement after stunning
  - Sound, such as vocalisations

Sensor technology and AI

- Thanks to the technological developments that have been achieved in recent years, it has become possible to generate data in livestock farming by means of sensors, such as cameras, microphones, speedometers, and thermometers.
- This data can subsequently be processed and analysed using computers and algorithms (AI). See Figure 1 for a graphic representation:

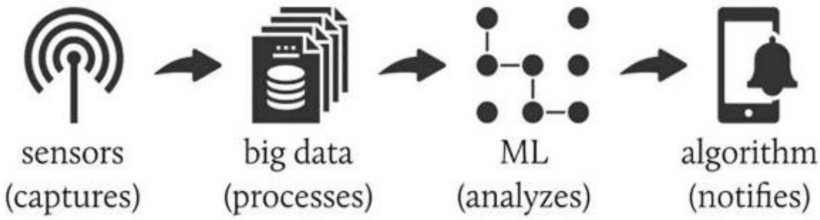

Figure 1 Graphic representation of the principle of sensor technology in combination with AI and precision livestock farming from Neethirajan (2020). A large volume of data is produced by means of sensors. This data is analysed by way of advanced machine learning (ML) algorithms and notifies users, such as livestock farmers, of any abnormalities.

- Automatic image analysis (moving and still images recorded by a camera) and sound analysis (sound recorded by a microphone) are forms of sensor technology that can be used to assess animal-based measures at slaughterhouses.

Applications of sensor technology and AI for measuring animal welfare at slaughterhouses

- Based on the literature review, various examples have been found on the use of sensor technology combined with AI to measure animal welfare at slaughterhouses. See Table 1 for an overview.

- A distinction can be made between application in scientific research and within systems that are currently already being used in commercial settings.
- The technologies used at slaughterhouses can be divided into measurements conducted on the carcass during PM inspection and measurements taken in live animals on arrival at the slaughterhouse.

Table 1 Overview of examples of initiatives in research and in practice relating to sensor technology in combination with AI and the measuring of animal welfare employed at the slaughterhouse. 'x' is in use; '-' is no study or commercial application known to BuRO.

Animal species	Measurement focus	Scientific research	Commercially available
Measurements in live animals			
Pigs	Abnormal movement	X	Vion and Dutch Society for the Protection of Animals in collaboration with Deloitte[4].
Measurements carried out on the carcass			
Pigs	Bleeding	X	VisStick system (DK), CLK GmbH (DE) and Vion
	Movement as a sign of consciousness	-	Deloitte AI4 Animals
	Tail length	-	Vion and CLK GmbH (DE)
	Tail lesions	X	CLK GmbH (DE)
	Ear lesions	X	CLK GmbH (DE)
	Cardiac disorders	X	-
	Liver disorders	X	-
	Pulmonary disorders	X	Italian start-up[5]
Veal calves	Meat colour (relationship with Hb levels)	X	Spectrometers Kiwa CBS classifiers (Kiwa, 2021)
Poultry	Footpad lesions	X	Meyn and CLK GmbH
	Broken wings	-	Multiple systems
	Redness and bruises	-	Multiple systems
	Skin damage	-	Multiple systems
	Carcass weight	-	Multiple systems

Possibilities of sensor technology for measuring animal welfare at slaughterhouses

- Based on published studies, the possibilities for the automatic recording of animal-based measures at the slaughterhouse currently appear to lie primarily in the areas of:
  - Image analysis to determine carcass abnormalities at the individual animal level
  - Image analysis for measurements in groups of animals, such as abnormal movements during unloading, aggressive behaviour or the distribution of animals within the space in relation to heat stress.

[4] The Dutch Society for the Protection of Animals (Dierenbescherming) intends to make this mandatory for the Better Life (Beter Leven) quality label and also to develop this system for cattle and poultry.
[5] Working on developing a commercially available system and on recognition of other diseases in pigs https://www.f4tlab.com/adal

  - Noise analysis such as the measuring of vocalisations as indicators of stress for example in the waiting pens, during rounding up or stunning.
- An overview of the possibilities in the short (next 1-2 years) and medium (2-5 years) term at poultry, cattle and pig slaughterhouses appears in Figures 2, 3, and 4.
  - Short term: systems that studies have proven to be applicable at the slaughterhouse and/or are commercially available.
  - Medium term: systems where studies have shown that one or more animal-based measures can be assessed using sensor technology, but which have not yet been applied at slaughterhouses (for this animal species). More research is needed in actual application at commercial slaughterhouses.

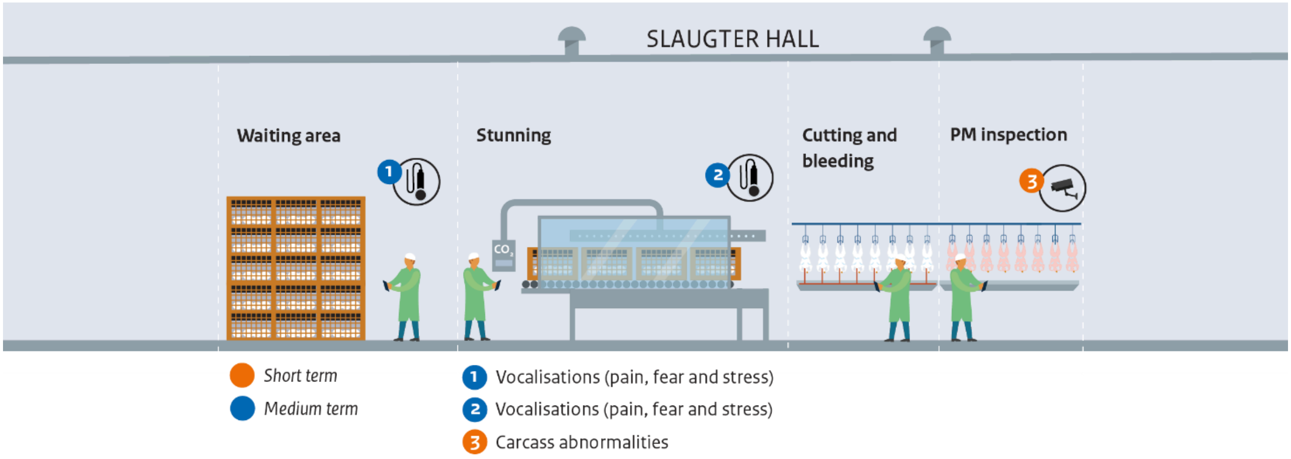

Figure 2 Possibilities in poultry slaughterhouse for sensor technology for measuring indicators of animal welfare, in the short and medium term.

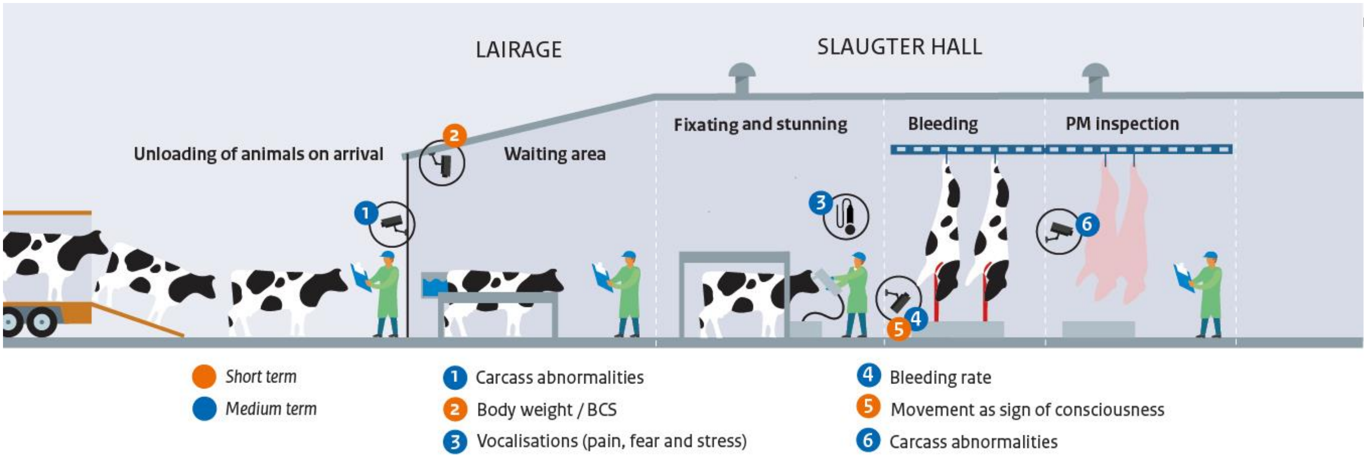

Figure 3 Possibilities in cattle slaughterhouses for sensor technology for measuring indicators of animal welfare, in the short and medium term.

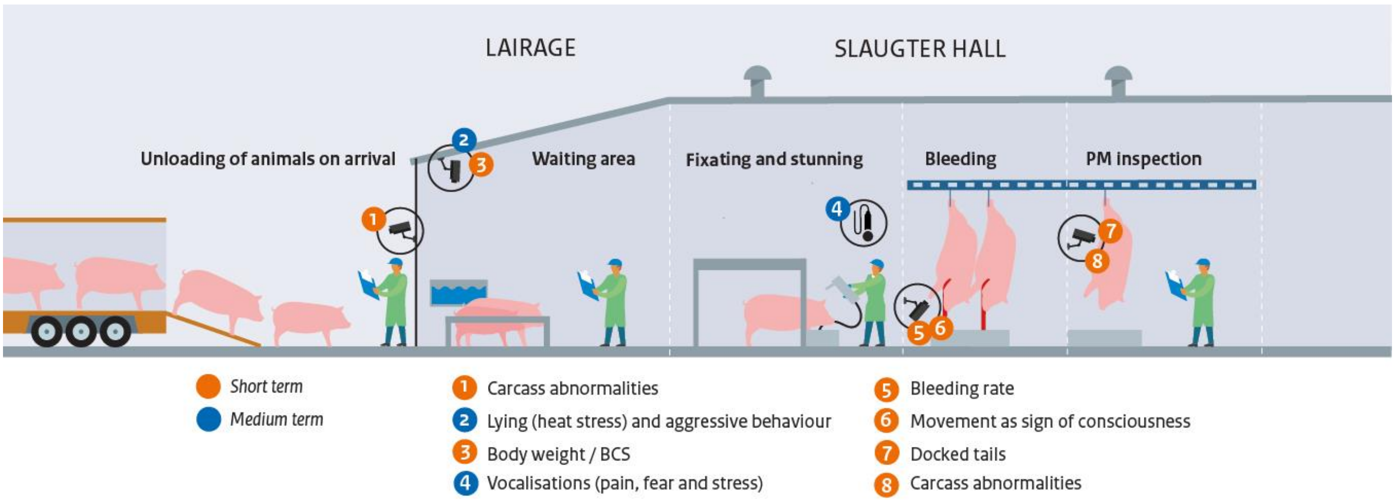

Figure 4 Possibilities in pig slaughterhouses for sensor technology for measuring indicators of animal welfare, in the short and medium term.

- In the short term, possibilities are focused mainly on applications relating to the welfare of poultry and pigs. Sensor technology combined with AI can be used by slaughterhouses to monitor animal welfare, and where necessary to introduce improvements, or to give feedback to the livestock farmer.
- In the medium term, possibilities are focused mainly on the automatic measuring of vocalisations as indicators of pain, fear and stress during the slaughtering process. Applications relating to the welfare of cattle at the slaughterhouse also offer possibilities.

Opportunities and limitations of sensor technology for measuring animal welfare

<u>Opportunities</u>

- Sensors make more constant and more accurate measurements than humans
- Sensors are relatively cheap and simple
- A sensor measures objectively and in a standardised manner
- Combination of sensors or measurements possible
- Captured data can be analysed (automatically)
- No direct contact with animals or carcasses is required
- Animal-based measures for groups of animals can be assessed
- No additional stressor
- Possible positive effect on conduct of slaughterhouse staff

<u>Limitations</u>

- Software can be expensive
- Innovative solutions for data storage and processing is required
- Development (algorithm training) requires extensive preparation
- Tailored approach is required for individual sites
- As yet there are no agreements on validation in the scientific community or within government
- Quality of the gold standard (validation of animal-based measures used)
- Sensor location: not everything can be recorded
- Disruption of recordings due to changing lighting conditions, dirt or dust
- A sensor technology application combined with AI only measures one single aspect
- Sensor technology combined with AI does not establish standards; limit values and classification must be determined separately
- Rules (GDPR) on privacy for slaughterhouse staff

Possibilities and prerequisites for the use of sensor technology and AI by the NVWA

- Sensor technology in combination with AI offers possibilities to support the work of the NVWA:
  - For the gathering and automated analysis of data (monitoring animal welfare risks).
  - For focusing supervision.
  - The supervisory authority (human) could then limit its focus to matters that are not measured by the sensor technology systems combined with AI or on non-conformities identified by the system.
  - Data from the systems that are already commercially available and present in slaughterhouses could be used (on an anonymous basis) to identify the prevalence of various types of welfare consequences, such as broken wings, bruises and skin damage in poultry.
  - If the criteria are satisfied, sensor technology combined with AI could, for example, become part of secondary supervision by the NVWA and/or part of an approved quality system.

- Sensor technology in combination with AI could contribute to making the NVWA's supervision more effective and efficient. In the short term this is complicated by a number of reasons:

- Controls at slaughterhouses must be conducted according to the European Controls Regulations (CoVo) (Regulation (EU) 2017/625)[6] by an official veterinarian or under the supervision of the official veterinarian.
- A sensor technology system combined with AI will often only measure one or two abnormalities, but a supervisor will still have to be present to identify any other abnormalities
- At present, there is not yet a legal basis for the use of camera-based monitoring and sensor technology combined with AI at slaughterhouses and regular camera surveillance has been introduced at medium-sized and large slaughterhouses on a voluntary basis.
- For the use of sensor technology with AI in enforcement, this legal standard must be measurable – a closed standard, i.e. a quantitative goal-oriented standard. Much legislation and regulations relating to animal welfare however, is made up of qualitative goal-oriented standards, also known as open standards.
- Existing systems and data are not the property of the NVWA. The NVWA currently depends on the cooperation of slaughterhouses for the use of data (with the statutory requirement for data on footpad lesion scores being an exception).
- Developing a trained and properly functioning system combined with AI and drafting and checking algorithms and external validation takes a great deal of time.
- The most common commercially available systems have not (yet) been externally validated[7].

Sensor technology and BuRO

- Sensor technology combined with AI is one of the spearheads of BuRO for the coming years, and is aimed at both increasing the knowledge network and knowledge of the relevant AI and machine learning applications and (commissioning) the development and validation of algorithms. In collaboration with other NVWA departments, specific experiments or POCs (Proofs of Concept) will be launched in the field of sensor data, AI and animal welfare, with the aim of developing knowledge to be able to systematically use data from slaughterhouses, for example for benchmarking and/or identifying the risks at the slaughterhouse, during transport or at the farm.

Conclusion

The use of sensor technology at the slaughterhouse to measure animal welfare offers myriad opportunities. A great deal can already be achieved from a technological perspective. A number of applications at the slaughterhouse are already commercially available or in use in research. Based on published studies, the possibilities for the automatic recording of animal-based measures at the slaughterhouse currently seem to lie mainly in the area of image analysis to determine carcass abnormalities or for measurements in groups of animals, such

[6] REGULATION (EU) 2017/625 OF THE EUROPEAN PARLIAMENT AND THE COUNCIL of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products, amending Regulations (EC) No 999/2001, (EC) No 396/2005, (EC) No 1069/2009, (EC) No 1107/2009, (EU) No 1151/2012, (EU) No 652/2014, (EU) 2016/429 and (EU) 2016/2031 of the European Parliament and of the Council, Council Regulations (EC) No 1/2005 and (EC) No 1099/2009 and Council Directives 98/58/EC, 1999/74/EC, 2007/43/EC, 2008/119/EC and 2008/120/EC, and repealing Regulations (EC) No 854/2004 and (EC) No 882/2004 of the European Parliament and of the Council, Council Directives 89/608/EEC, 89/662/EEC, 90/425/EEC, 91/496/EEC, 96/23/EC, 96/93/EC and 97/78/EC and Council Decision 92/438/EEC (Official Controls Regulation), OJ L95, 7.4.2017, pp. 1–142.
[7] The Meyn Footpad Inspection System and the German system for ear and tail lesions in pigs developed by CLK GmbH have been validated, for example.

as abnormal movements during unloading, aggressive behaviour or the distribution of animals within the space in relation to heat stress. The measuring of vocalisations as an indicator of stress, for example in the waiting pens, during driving or stunning, also offers possibilities. This ties in with the risks to animal welfare that are estimated to be highest.

Sensor technology combined with AI is **not yet** expected to be used as a replacement by the NVWA in the enforcement domain in the short and medium term. This is due to the absence of a legal requirement, the fact that not all data from the slaughterhouses can be used as yet and because the existing systems have not yet been externally validated. In addition, animal welfare often deals with open standards, meaning that no fixed target values are available.

Within a number of years, sensor technology could make an indirect contribution to more effective supervision by using the gathering of data for risk-based supervision. Consistent and continual information and data gathering will allow the NVWA to obtain more accurate information on the prevention of certain types of welfare consequences and thus better identify the welfare risks. This information could be used when focusing supervision. However, the gathered data will then have to be available to the NVWA.

Advice

<u>For the NVWA's IG</u>

Short term:

1. Call upon slaughterhouses already measuring animal welfare using sensor technology and/or AI to specify how animal welfare risks can be measured and safeguarded using these systems.
2. Focus on further encouraging slaughterhouses to use sensor technology and AI systems that have been externally and independently validated, to measure and improve the safeguarding of animal welfare.
3. In collaboration with slaughterhouses, focus on the possibilities referred to in these advices for the use of sensor technology and AI and other high-opportunity initiatives for improving animal welfare.
4. In the context of expectation management, communicate the fact that the use of sensor technology combined with AI at slaughterhouses for animal welfare will not result in greater effectiveness and efficiency in enforcement in the short term, but will mainly relate to gaining experience and acquiring a better insight into the viability, opportunities and limitations of these systems.

Medium term:

5 Together with the policymakers, use the knowledge developed for developing benchmarks and possible standards for animal welfare, on the basis of the sensor technology employed in combination with AI. Also investigate the possible amendment of legislation and regulations on this subject.

Yours faithfully,

Office for Risk Assessment & Research (BuRO)
Prof. Antoon Opperhuizen

Substantiation

1. Animal welfare and the NVWA

1.1. Welfare within the chain

The assessment of animal welfare takes place in three distinct phases: 1) farm?, 2) Transport, and 3) Slaughterhouse. Within these phases, there are various components on which animal welfare can be assessed.

The livestock farmers, transporter and slaughterhouse personnel bear primary responsibility for the welfare of the animals. The NVWA conducts monitoring of animal welfare based on the applicable laws and regulations. The aforementioned components are housing, water and feed, animal health at the farm, welfare during transport, upon arrival at the slaughterhouse, in the waiting pens, and when securing, stunning and bleeding animals. The figures below provide a schematic overview of the process.

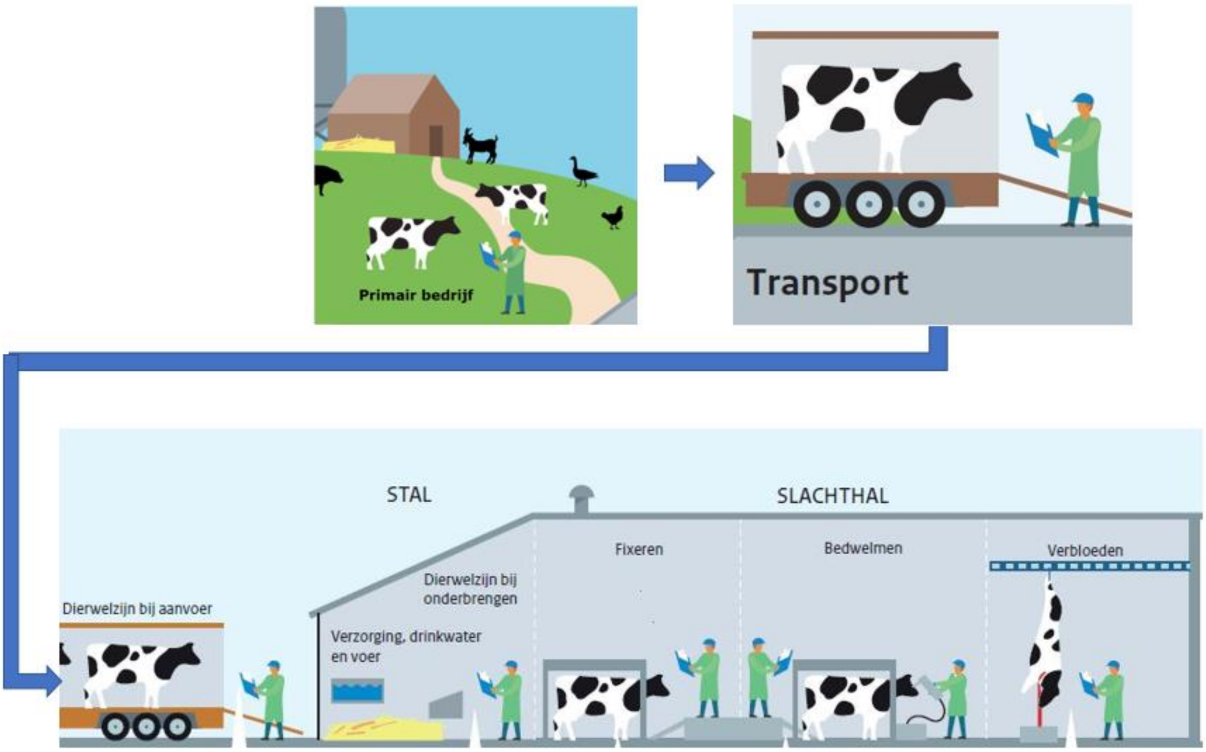

Figure 5 NVWA supervision of animal welfare at the slaughterhouse in the red meat chain.

Figure 6 NVWA supervision in the poultry chain (farm, transport and slaughterhouse).

1.2. NVWA supervision and inspection at the slaughterhouse

In 2019,there were 199 slaughterhouses in the Netherland(NVWA, 2020a). Around 624.7 million animals are slaughtered at these slaughterhouses each year, of which poultry is by far the largest group of animals (606 million animals in 2020), followed by pigs (15.9 million animals in 2020) and veal calves (1.5 million animals in 2020)[8]. In 2020, there were 20 red meat slaughterhouses subject to permanent supervision (90% of slaughtered pigs, cattle, calves, sheep, goats and horses) and 18 large poultry slaughterhouses (99% of all slaughtered poultry) (NVWA, 2021a).

Upon arrival at the slaughterhouse, all animals (individually or at herd/flock level) receive an AM (ante mortem) inspection from an NVWA veterinarian. Additional supervision at the slaughterhouse will also depend on the number of animals slaughtered per week, the number of animal slaughtered per hour and the animal group. Slaughterhouses may be subject to permanent supervision, monthly or weekly supervision. Please see Appendix 2 for additional information. The post mortem (PM) inspection is carried out by the Animal Sector Quality Inspection Foundation (KDS) under the supervision of the NVWA. Due to the high speed at which the slaughter process takes place, there is very little time available per animal/carcass during the inspection – particularly in the case of poultry. In the case of broilers, more than 3 chickens are presented for PM inspection on the slaughter line each second (Jørgensen, 2018). Key components in relation to food safety include hygiene, carcass abnormalities and sick animals. This is assessed during the AM and PM inspection and during the remainder of the supervision at the slaughterhouse. The handling of the animals, the killing process and the

[8] Responses to written questions alongside the Final Budget Amendment Act for the Ministry of Agriculture, Nature and Food Quality and Animal Health Fund (35830-XIV, No. 4).

condition of the animals are parameters relevant to animal welfare and are primarily examined during the AM inspection and during the remainder of the supervision at the slaughterhouse (NVWA, 2021b). Appendix 3 contains a full breakdown of the supervision and monitoring carried out by the NVWA at poultry slaughterhouses.

It is difficult for the NVWA to employ a sufficient number of supervising veterinarians. There are a large number of permanent vacancies and practitioners (practicing veterinarians who carry out official duties in an employee-employer relationship) are used to fill the gaps; in addition, veterinarians are recruited from other EU countries (Bergevoet et al., 2020). The available veterinarians therefore must be allocated as efficiently as possible. In addition, ensuring uniformity in enforcement and monitoring is key.

1.3. Animal welfare risks

To ensure the most effective use of sensor technology, it is vital to examine at the greatest risks to animal welfare that can be measured at the slaughterhouse.

1.3.1. <u>Risk assessments by BuRO</u>

BuRO has carried out various risk assessments of production chains in recent years, in which farm animals were part of the chain. In these chain assessments, the risks in the many links of the production chain are assessed from the animals on the farm to the products on consumers' plates. The international scientific literature on food safety and animal welfare was collected for this purpose, its relevance for the Dutch production chain evaluated and the risks assessed – as far as possible -. The risk assessment of the red meat chain was the first to be published in 2015 (BuRO, 2015), followed by that of the diary chain in 2017 (BuRO, 2017) and that of the poultry meat chain and the egg chain in 2018 (BuRO, 2018a;2018b). 2022 will focus on the red meat chain 2.0.

1.3.2. <u>Risk assessment method</u>

The risk assessments carried out by BuRO[9] are based on the EFSA risk assessment methodology (EFSA, 2009;2012c;2012b). EFSA's methodology is in line with the 'Food Code' (Codex Alimentarius)(FAO/WHO, 1995) and Regulation (EC) 178/2002[10]. The risk assessment consists of the following steps:

1. Hazard identification: the threats to animal welfare that have been identified by academic experts and experts in professional practice and which have been described in international scientific literature,
2. Hazard characterisation: the relevance (welfare impact), consisting of the severity and duration of welfare consequences, arising as a result of the threat and the prevalence of welfare consequence (1)
3. Exposure assessment: the likelihood of threats, including the number of animals affected by them. In the case of animal welfare, this also includes the occurrence of conditions, situations and practices that affect the welfare of animals.

[9]The methodology for the assessment of risks is currently under development. The various risk assessments were not carried out in a uniform manner. The assessments take into account the risks that were deemed to be the highest using the method applied at the time. Due to the difference in approach, the various risk assessments cannot be compared with one another fully.
[10] Regulation (EC) No. 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. OJ L 31, 1.2.2002, p. 1–24.

4. Risk characterisation: the overall assessment of the nature and severity of each individual hazard alongside the probability of occurrence/prevalence in the Netherlands.

1.3.3. BuRO animal welfare risk findings

For a more detailed outline of the various animal welfare risks, we kindly refer to the risk assessments previously conducted by BuRO for the red meat, poultry meat, egg and dairy chains. In summary, based on these risk assessments, the advisory report on the evaluation of the Animals Act and the 2021 Risk Assessment Letter (BuRO, 2015;2017;2018a;2018b;2020b;2021), the greatest risks to animal welfare lie in the areas of nutrition, housing and health, with the associated welfare consequences ranging from diseases and disorders to limited or undesirable animal behaviour. Whereas (intensively) reared poultry appear to be primarily affected by disorders and undesirable types of behaviour, dairy animals often seem to be suffer from metabolic problems (such as rumen acidosis, diarrhoea, (lingering) milk fever) (BuRO, 2021). Most of the welfare consequences in the primary phase related to 'good health' and to the presence of disease in particular. In addition, a significant share of the welfare consequences is caused by 'pain from management interventions'. Welfare consequences in respect of 'normal behaviour' are likewise common, particularly as regards a limitation in the performance of species-specific behaviour (BuRO, 2020b).

During transport to slaughter, a combination of careless conduct on the part of (external) personnel during the catching and loading process, insufficient precautions during transport as well as inadequate equipment of transportation play a major role. Furthermore, heat stress during transport of broilers and finishing pigs constitutes a serious risk during very warm periods (BuRO, 2021).

Small percentages of animals, particularly poultry, including end-of-career laying hens, experience severe welfare consequences as a result of 'slaughter' as a whole, which, for example, relate to inadequate slaughter facilities, inadequate killing procedures and failure to intervene in time in the event of incorrect use (BuRO, 2021).

2. (Animal) indicators at the slaughterhouse

2.1. Animal welfare indicators

The welfare of an animal is affected by its physical environment and the resources available to the animal, such as the available space, type of housing, bedding, quality and quantity of feed, etc. These are resource-based measures or environmental factors. The management exercised by the livestock farmers, i.e. the management factors (management-based measures) likewise play a key role, for example, in terms of how often feed is provided or pain relief is made available. In addition to these factors, the characteristics of the animal itself, such as age, breed and sex play a key role in terms of how the animal copes with a stressor and how the welfare of the animal is impacted. The outcome may have a positive as well as a negative impact on the animal. A risk assessment examines the adverse effects of these factors and will also refer to 'hazards'. These factors cause a response and an effect in the animal, namely the welfare consequence. This consequence in the animal can be measured using an animal indicator (animal-based measures) (EFSA, 2012d). Please see the figure below for schematic representation. The positive consequences are not addressed or discussed in this advisory report.

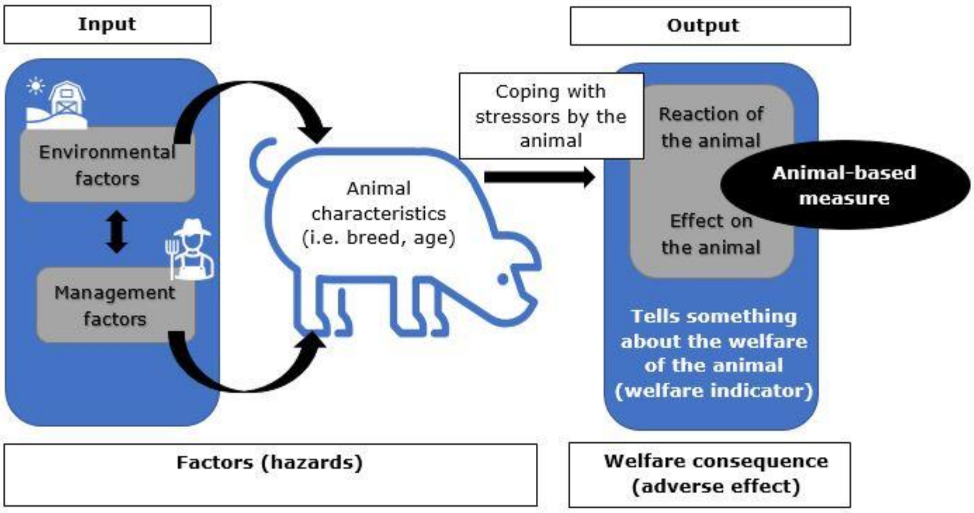

Figure 7 Overview of the relationship between various factors impacting the welfare of the animal and the indicators. Based on EFSA (2012d).

2.2. Animal-based measures

Animal welfare deals with the state of wellbeing and welfare of individual animals. The impact of a situation can therefore best be measured on the animal itself by means of animal-based measures (Velarde & Dalmau, 2012; Maisano et al., 2020). An animal-based measure is an animal's response or an effect of a situation on an animal that is used to assess its wellbeing. The indicator can be read directly from the animal at the farm, ante mortem (AM) or post mortem (PM). Examples of direct indicators include behaviour, physical condition or blood values. Animal-based measures may also be indirect in nature and include the use of animal data such as mortality rates. An animal-based measure may be the result of a specific event, such as an injury, or the cumulative effect of many days, weeks or months, such as an animal's physical condition or the development of abnormal behaviour (EFSA, 2012d;2012e).

The indicators may be physiological in nature (such as measuring hormone levels, heart rate or blood values), morphometric (such as body weight) or may be measured on the basis of behaviour (such as vocalisations or difference in movement) (Losada-Espinosa et al., 2018).

The potential for multiple interactions to take place between factors, welfare consequences and animal-based measures should be taken into account in this regard. There may not always be a clear link. Various hazards may lead to the same welfare consequence, with one specific welfare consequence impacting another welfare consequence (e.g. lame cows being more recumbent in nature, which increases the probability of mastitis in the case of insufficient hygiene) or an animal-based measure may be a sign of a variety of welfare consequences at play. When selecting animal-based measures, it is therefore crucial to be aware of these interactions in order to select the best combination of indicators. For that reason, animal-based measures must meet the criteria of validity, sensitivity, specificity and robustness. The animal-based measure must be able to identify a specific welfare consequence and must be repeatable and reliable. If this is the case, a combination of different animal-based measures provide an effective and robust way of assessing animal welfare (EFSA, 2012d;2012e).

Animal-based measures can be combined with environmental and management factors in order to enhance reliability. One example in relation to heat stress: high ambient temperatures and high humidity levels play a key role in the development of heat stress. Panting is an animal-based measure of heat stress. When an animal is panting and the ambient temperature and humidity levels are high, it is likely that the animal is experiencing heat stress. If an animal is panting but ambient temperature and humidity levels are low, then the panting may, for example, also be caused by physical exertion or illness.

2.3. Animal-based measures at the slaughterhouse

Animal-based measures at the slaughterhouse can be assessed at various points: when unloading the animals, in the waiting pen, when rounding up, stunning or killing the animals and based on the carcass post mortem (Dalmau et al., 2009; Dalmau et al., 2016). Animal-based measures that are assessed at the slaughterhouse include lesions (such as skin, tail, shoulder or footpad lesions), signs of illness (such as coughing, sneezing, laboured breathing, skin inflammation), lung, heart, liver pathology, bruising or locomotion and body condition score (BCS) (EFSA, 2012e;2012a; Romero et al., 2020; De Luca et al., 2021).

An animal-based measure assessed at the slaughterhouse can provide information regarding the welfare of the animal at that specific time at the slaughterhouse as well as information about the animal's past welfare at the farm, during transport or a combination of those phases (EFSA, 2012d).

2.3.1. Animal welfare at the farm assessed at slaughterhouse

Some indicators of animal welfare at the farm are easier to measure at the slaughterhouse than on the farm. These indicators, for example, only will become visible during a PM inspection, such as stomach lesions or pulmonary disorders in pigs or veal calves. The post mortem inspection at the slaughterhouse is a strategic point within the chain. Inspection of carcasses is required by law for food safety reasons and animals are brought together at a slaughterhouse in large numbers from a variety of farms. The welfare of animals from multiple farms can therefore be assessed at a single location, which can be fed back to the farmer, but can equally be used for epidemiological studies (Trachtman et al., 2020; De Luca et al., 2021).

Examples of animal-based measures assessed at the slaughterhouse that provide information about the welfare at the farm include lung, heart and liver disorders in pigs or emaciated animals, breast blisters, footpad lesions, abscesses, dehydration or inflammation of organs such as the heart or liver in broilers (Welfare Quality®, 2009c;2009a). A key criterion is that, in this case, these indicators should not be affected by the conditions during the capture, transport and slaughter of the animals or can arise acutely. Footpad lesions in broilers, for example, are not affected by transport, however, bruising and broken bones are (EFSA, 2012a).

2.3.2. Animal welfare during transport assessed at slaughterhouse

Transport is a stressful event for animals. The combination of this stress with the handling of animals by humans during the unloading of animals at the slaughterhouse may cause welfare consequences. This is what makes the slaughterhouse an important place to measure animal welfare (Dalmau et al., 2009; Dalmau et al., 2010).

2.3.3. Animal welfare at the slaughterhouse

Animal welfare measured in a specific place provides information about the wellbeing of the animal at that specific time. In order to get an overall picture of animal welfare at the slaughterhouse, welfare must be assessed at multiple points within the slaughterhouse (Dalmau et al., 2010). Some indicators can therefore be measured during the unloading process, in the waiting pen, when driving up the animals and/or during the stunning and killing process, whereas others are only measured from the carcass. Different animal-based measures will be relevant to each individual phase. In the USA, animal-based measures have long been used in animal welfare audits at the slaughterhouse on behalf of major restaurant chains. Aspects that are examined will, for example, include the percentage of animals that fall during the unloading or rounding up process, the percentage of animals that vocalise during the rounding up or in the stun box, or the percentage of animals that have been stunned properly the first time (Stocchi et al., 2014; Grandin, 2021). Audits on behalf of large restaurant chains, such as McDonalds, are similarly carried out at slaughterhouses in the Netherlands in order to verify whether the slaughterhouses meet the animal welfare requirements of the chains (Vion, 2021).

Actions by slaughterhouse staff, such as the use of electrical prods are also often part of these audits (Grandin, 2010). This and other forms of interaction with the animals by slaughterhouse staff are factors that influence animal welfare, and can result in animal welfare consequences such as pain, fear and stress, measurable using animal-based measures such as falling animals and vocalisations (Losada-Espinosa et al., 2018). Because of the focus on animal-based measures, actions by slaughterhouse staff are not included as a separate element of these advices; the focus here is on the animal.

2.3.4. Welfare Quality and animal-based measures to be assessed at the slaughterhouse

The European concept of Welfare Quality was developed from the point of view of assessing animal welfare within the animal husbandry system and is divided along four key principles: nutrition, housing, health and behaviour, with the following corresponding questions (Botreau et al., 2007):

- Are the animals sufficiently fed and provided with water?
- Are the animals properly housed?
- Are the animals healthy?
- Does the animals’ behaviour reflect optimised emotional states?

These principles and criteria have been fleshed out into assessment protocols for various animal species, including for cattle, pigs and poultry(Welfare Quality Network, 2019). In these protocols, welfare is assessed as much as possible using animal-based measures. These animal-based measures are assessed at the farm as well as at the slaughterhouse.

Based on recent EFSA reports on the welfare of poultry, cattle and pigs at the slaughterhouse (EFSA, 2019;2020a;2020b) and Welfare Quality protocols (Welfare Quality®, 2009b;2009c;2009a), an assessment was drawn up of animal-based measures and the associated welfare consequences that can be measured at the slaughterhouse. See the tables in Appendix 4 for an overview.

In summary, the animal-based measures can be classified into three categories:

1. Abnormal still image, e.g. pathology or bruising
2. Abnormal moving image of the animal, e.g., lameness, falls or movement after stunning
3. Sound, such as vocalisations

Aspects of welfare at the farm can best be assessed at the slaughterhouse on the basis of various pathological abnormalities. In poultry and pigs, these abnormalities have been identified by EFSA and Welfare Quality and include footpad lesions and hepatitis in poultry and pneumonia and pleurisy in pigs. These types of abnormalities have not been defined for cattle, but may naturally also occur. Serious respiratory problems at the farm, for example, can lead to lung damage in veal calves, which can be recognised at the slaughter line by way of abnormalities to the lungs and pleurisy (Brscic et al., 2012; Leruste et al., 2012; Heeres-van der Tol et al., 2017; Wageningen University & Research, 2018). The animal-based measures per animal species cited in the tables in Appendix 4 must therefore be regarded as examples rather than as an exhaustive list.

3. Sensor technology combined with AI and application in livestock farming

3.1. How does sensor technology work?

Thanks to the technological developments that have been achieved in recent years, it has become possible to generate data in livestock farming by means of sensors, such as cameras, microphones, speedometers and thermometers (Rushen et al., 2012; Norton & Berckmans, 2018; Benjamin & Yik, 2019; Van Erp-van der Kooij & Rutter, 2020; Herlin et al., 2021).

The sensor measures an aspect of the environment or of the animal itself. The sensor may be attached to the animal, such as an ear tag, or be situated in the animal's environment, such as a camera. This data can subsequently be processed and analysed using computers and algorithms, from which valuable information can be obtained. The data can then be compared with a target value and, for example, flag whenever the data deviates from the target value. Action can then be taken based on this signal. This is part of precision livestock farming (PLF) (Rushen et al., 2012; Norton & Berckmans, 2018; Benjamin & Yik, 2019; Van Erp-van der Kooij & Rutter, 2020; Herlin et al., 2021). Please see the figure below for a graphic representation:

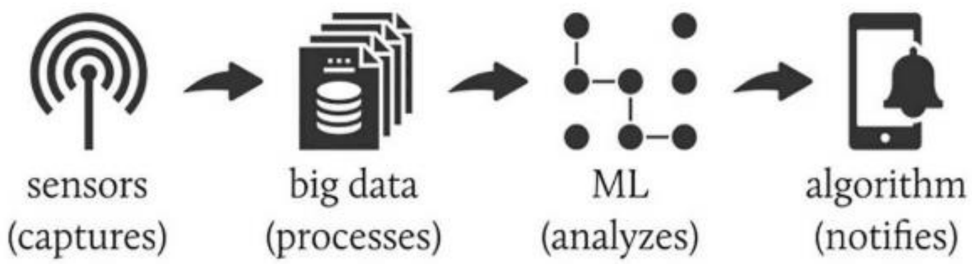

Figure 8 Graphic representation of the principle of sensor technology combined with AI and precision livestock farming from Neethirajan (2020). A large amount of data is produced by

means of sensors. This data is analysed by way of advanced machine learning (ML) algorithms and notifies users, such as farmers, of any abnormalities.

Many of these technologies are already commercially available for the farm, such as pedometers for dairy cattle, a camera that measures the body condition score or for automatic registration of feed intake (Van Erp-van der Kooij & Rutter, 2020). Measuring systems that are linked to an individual animal, such as pedometers or sensors in the ear tag, are not suitable for the measurement of animal-based measures at the slaughterhouse, including due to the large numbers of animals, the manual attachment of the sensor to the animal and the significant cost of each sensor.

The number of publications on precision livestock farming has increased significantly in the last 20 years and in the past few years in particular (Rowe et al., 2019; Larsen et al., 2021), with 63% of the scientific publications on precision livestock and animal welfare in pigs, for example, having been published in the last 5 years (Larsen et al., 2021). In pigs, cameras (49%) and microphones (18%) are the most widely used type of technology in animal welfare studies. Most of the studies were carried out in the farm phase (Larsen et al., 2021). Poultry studies (not specifically related to welfare) relating to PLF likewise also frequently use cameras (42%) (Rowe et al., 2019). Both for pigs and poultry, most studies are related to the health of the animal (Rowe et al., 2019; Larsen et al., 2021). The literature review conducted by Rowe et al. (2019) on precision livestock farming in poultry farming shows that most studies (96%) relate to prototypes and only 10 papers (3.8%) relate to commercially available systems.

3.1.1. Automatic image analysis

The use of camera and the analysis of camera images is a form of sensor technology combined with AI. Cameras used for image analysis purposes can be divided into four categories: 1) Charge Coupled Device (CCD), 2) 2D cameras, 3) 3D, also known as depth, cameras and 4) Thermal infrared cameras (Nasirahmadi et al., 2017; Benjamin & Yik, 2019; Fernandes et al., 2020; Arulmozhi et al., 2021; Kang et al., 2021).

To a computer, a digital image consists of data that provides information about the light and the colour of each point in the image, which may be a simple black & white (binary) image, consist of various shades of grey (greyscale image), matrices and the intensity of red, green and blue in colour images or multiple matrices for hyperspectral imaging. Based on that data, studies can then be done using mathematical calculations and statistics and (machine learning) algorithms can be developed (Fernandes et al., 2020; Arulmozhi et al., 2021).

The various parts of a computer vision system are outlined in Figure 9.

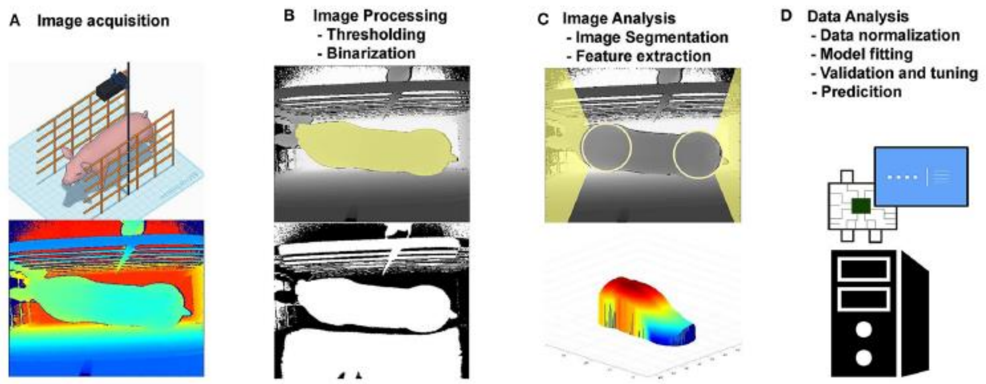

Figure 9 Example of a computer vision framework from Fernandes et al. (2020). A: image acquisition, B: image processing using image thresholding and binarisation, C: image analysis, identifying the head and tail of the pig, various measurements are taken from the pig's back. D: this data is used to develop a predictive model that, for example, predicts the body weight of pigs.

The first animal-based applications of computer vision were in the area of meat quality, such as fat content or the automatic sorting of meat (Fernandes et al., 2020). In recent years, systems have also been developed that are applied to live animals and/or are related to animal welfare. A number of examples are outlined in Chapter 4. Image analysis can be used to detect abnormal images or anomalous movements.

3.1.2. Automatic sound analysis

A microphone will convert sound into electrical signals, which are then converted and analysed by a computer to recognise acoustic events and categorise them according to indicators, such as illness or stress (Benjamin & Yik, 2019).

This analysis consists of several parts. 1) data transformation, segmenting the data blocks, 2) detection of the event, 3) calculation of the characteristics and 4) classification, the classification of previously labelled events based on the data. This analysis may, for example, look at the frequency (pitch in Hz), the power (in dB) and duration of the sound. Some of the events (e.g. the cry of a pig or the start or end of the clucking of hens) must be labelled manually first by a researcher in order to train the model(Vandermeulen et al., 2015; Du et al., 2020).

3.1.3. Underlying technology

Software such as machine learning and deep learning is being developed with the help of AI that simulates human intelligence (please see Figure 10 for a schematic representation). Human input, however, is still needed. Humans are required to establish the limit values or manually label the first set of data based on knowledge and experience. Using large datasets with these examples, an algorithm can then programme itself and learn from these examples. This strategy, for example, was used in the field of diagnostic imaging in human medicine and is already being used in research to identify abnormalities in pigs. Using convolutional neural networks (CNNs), pathological conditions are assigned to images and classified further using statistical methods. This is how the system is trained (Benjamin & Yik, 2019; Shimizu & Nakayama, 2020; Trachtman et al., 2020; De Luca et al., 2021).

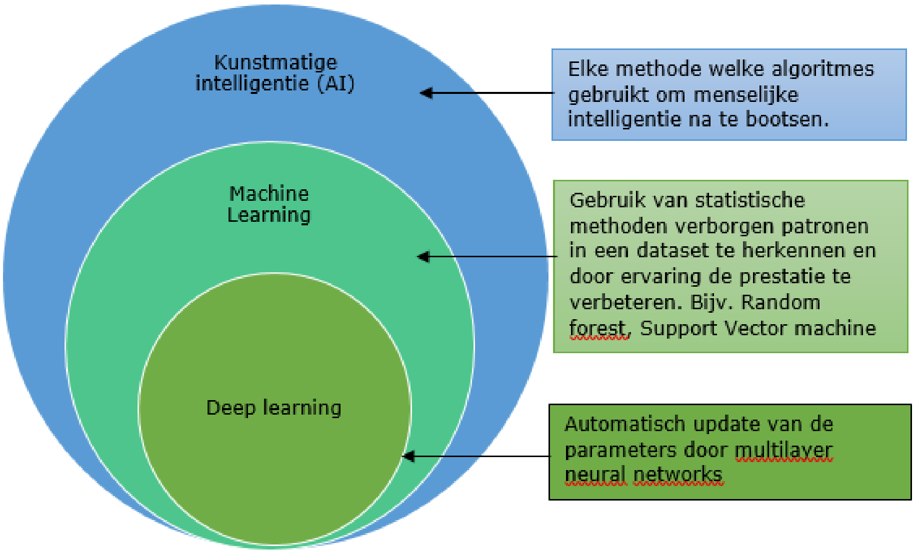

Figure 10 Deep learning and machine learning as part of artificial intelligence. Based on Shimizu & Nakayama (2020).

Various analysis methods are used in deep learning, such as Convolutional neural network (CNN), Optical Flow (OF), Support vector machine (SVM), Motion History Image (MHI), Linear Discriminant Analysis (LDA), Multilayer feed forward neural network, Modified angular histogram analyse (MAH), Linear prediction coding (LPC) and Self-organizing feature maps (SOFM). This advisory report will not examine the technical specifications of these analysis methods further.

3.1.4. Accuracy and reliability

Validation of a system is crucial. How accurately does the system measure when compared to the gold standard – for example, how well does a thermal camera measure ambient temperature compared to a thermometer (Gómez et al., 2021)? Assessing this may involve examining the accuracy or the correlation, which, in other words, focuses on: does the system measure what it is supposed to measure (Herlin et al., 2021). Accuracy consists of 1) sensitivity: the probability that a positive outcome of the system corresponds to the actual event and 2) specificity: the probability that no positive outcome is given in the absence of the event. This is often shown as a percentage (Rushen et al., 2012; Nasirahmadi et al., 2017; Blömke et al., 2020). Another statistical method to measure quality is to calculate the correlation coefficient (r) and the determination coefficient (r^2) between the actual value and the value measured by the sensor. R^2 shows what the proportion of variation is of a studied quantity (the actual state) that can be accounted for by one or more variables (the sensor signals) (Herlin et al., 2021). The r is between -1 and 1. And the r^2 is between 0 and 1. The closer to 1 (0r -1) the r or r^2, the stronger the relationship and the better the measurement results.

A comparison is also frequently drawn between the assessment of the human researcher and the applied technology, the degree of correlation also known as the reliability of the developed system (Blömke et al., 2020).

There are therefore several statistical methods available to determine the quality of a system. However, to date there are no fixed agreements or accepted methods within the scientific community to validate these systems (Herlin et al., 2021). In the Netherlands, the Netherlands Court of Audit (Algemene Rekenkamer (2021) has recommended that government-wide agreements be made regarding the quality and validation of algorithms.

There are three forms of validation (Gómez et al., 2021; Stygar et al., 2021):

1 External self-validation: the system is evaluated using a completely independent dataset that uses data of animals that was not used in the development of the system. Validation is performed by a researcher or employee involved in the development of the system.
2 External independent validation: the system is evaluated using a completely independent dataset containing data of animals not used in the development of the system. Validation is performed by an independent researcher who is not involved in the development of the system or has any relationship with the company that owns the technology.
3 Internal validation: the system is evaluated using the same dataset as was used to build the technology. The dataset is split into a test, training and validation dataset.

Of the PLF systems for pigs that are commercially available and validated, only 7% has been externally validated, with the remaining 93% having been internally validated (Gómez et al., 2021). For dairy cattle likewise only 14% of the PLF systems that are commercially available and have been validated were validated externally (Stygar et al., 2021).

4. Examples of sensor technology combined with AI and measuring animal-based measures

Based on the literature review, several examples were identified regarding the application of sensor technology combined with AI to measure animal welfare, with examples only being cited which were directly applied at the slaughterhouse and/or which relate to the aforementioned animal-based measures, but were studied in the primary phase (please see Chapter 2) and that can be measured at the slaughterhouse. It should be noted that these are examples and do not constitute an exhaustive overview of all applications of sensor technology combined with AI at the slaughterhouse to measure animal welfare: no full systematic literature review was conducted.

4.1.1. Body condition score and deviating weights

A lower body condition score or non-standard weight in a group of animals can be a sign of reduced welfare at the farm (Welfare Quality®, 2009c; Grandin, 2010; Losada-Espinosa et al., 2018; Maisano et al., 2020). Non-uniform groups are a relevant parameter for animals kept for meat such as broilers, fattening pigs and meat calves. A low body condition score is in particular relevant for end-of-career animals such as dairy cows and sows.

In particular for pigs and also cattle, many studies have been conducted into the automatic estimation of the weight using a camera and AI (Gómez et al., 2021; Larsen et al., 2021; Silva et al., 2021).

There are a number of commercially available systems for pigs (Pezzuolo et al., 2018), such as apps and a hand scanner. By taking a photograph using the app, according to an algorithm, the weight of the pig is determined (Ymaging, 2015; H+L, 2022; WUGGL, 2022). Other applications such as GroStat and eYeGrow consist of a camera suspended above the pen that photographs the pig in order to determine the weight (Fancom BV, 2022; GroStat, 2022). For dairy cattle there is a commercially available system for determining the body condition score using a 3D camera (DeLaval, 2015; Stygar et al., 2021). This system was validated by Mullins et al. (2019). The system is reliable for cattle with an average body condition score (3-3.75), but less accurate for animals with a low or high body condition score. The researchers expect that reliability will be improved in the future, with the development of the algorithm and software updates.

It is already technologically possible to estimate the weight of an animal using cameras and AI. The question is whether slaughterhouses will invest in this technology. After all, the carcass is already weighed following the slaughtering of the animal. However, this yields the carcass weight, from which the organs have already been removed, and in the case of cattle also the head, skin and part of the fat[11]. However, the carcasses are not weighed on the basis of AI, but the process is automated. One example is the ChickSort system, in which individual poultry carcasses are weighed and an overview of the weights provided per flock. This information can be linked to information about other non-conformities in the carcass, such as broken wings and bruising (Foodmate B.V, 2021). One advantage of assessing the weight of the live animal is that the condition, welfare and health of the live animals can be assessed, instead of only the weight after slaughter.

4.1.2. Thermal stress and lying behaviour of pigs

The lying behaviour of pigs is an animal-based measure for thermal stress. When animals lie close together, this is a sign of cold stress, whereas when animals are lying at a significant distance from one another this is a sign of heat stress (Dalmau et al., 2009; Welfare Quality®, 2009a; EFSA, 2012e; Dalmau et al., 2016; EFSA, 2020a). Shao & Xin (2008) have used a real-time image processing system to identify movement and thermal comfort based on resting behaviour of pigs in group housing. In the study, the system was able to classify more than 90% of the images into the correct category of cold, comfort zone or heat. Nasirahmadi et al. (2015) have likewise studied the lying behaviour of pigs using machine vision. Images were taken from the top of the pen. A pig was identified as an elliptical shape with an x and y axis and using the Delaunay Triangulation a calculation was able to be made of how close to each other the pigs were lying, i.e. the Mean Value of Perimeters (MVP). The temperature in the room was measured with several temperature sensors. The MVP increases as temperatures increase and at higher temperatures pigs were found to be lying further apart from one another.

[11] Rules on meat market regulation, BWBR0034313

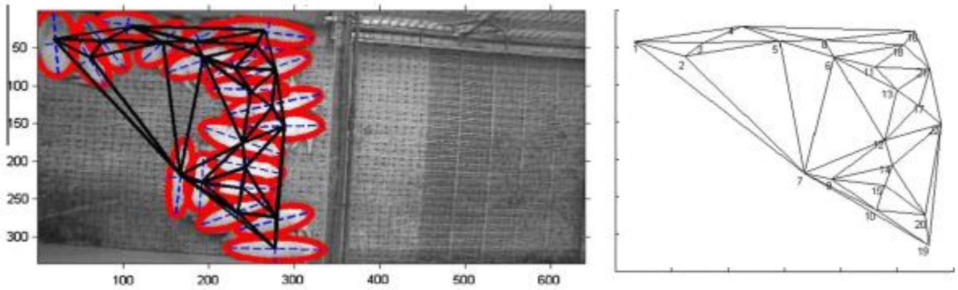

Figure 11 Calculation of the Delaunay triangulation by identifying pigs as ellipses from Nasirahmadi et al. (2015).

These examples show that these technologies provide opportunities for the recording of heat or cold stress in pigs in the waiting pen at the slaughterhouse. These measurements can be reinforced by recording other (animal) indicators such as panting and the ambient temperature.

4.1.3. Lameness

Various pressure plates and pressure-sensitive mats, have been developed which, for example, can detect lameness in pigs and cattle (Benjamin & Yik, 2019; Van Erp-van der Kooij & Rutter, 2020; Kang et al., 2021). These technologies, however, require that the animal stand still for a longer period of time on the plate or walk across the mat at a fixed pace (Meijer et al., 2014; Benjamin & Yik, 2019). The animal must not run, slip or stop (Maertens et al., 2011). This makes this technique less suitable for use at the slaughterhouse.

Lameness in cattle can also be detected by means of computer vision, for example, using a 2D camera, a 3D camera or a thermal infrared camera. Examples include the computer vision process and automatic score for lameness in figures 12 and 13. 2D cameras have to capture the side of the animal and are sensitive to changes in the light. The advantage of a 3D camera or thermal infrared camera is that these cameras provide more information, such as depth and temperature, and can be positioned above the animal, resulting in less space being needed. The principal advantage of automatic lameness detection using computer vision is the fact that the method is relatively inexpensive and does not require direct contact with the animals (Kang et al., 2021).

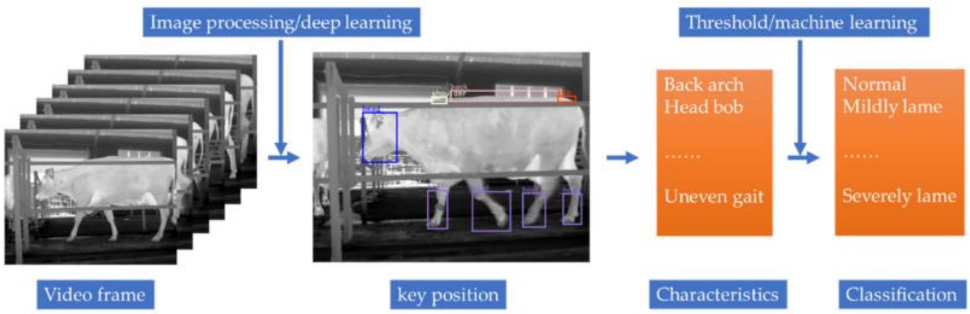

Figure 12 The process of computer vision and lameness scoring with a 2D camera from Kang et al. (2021).

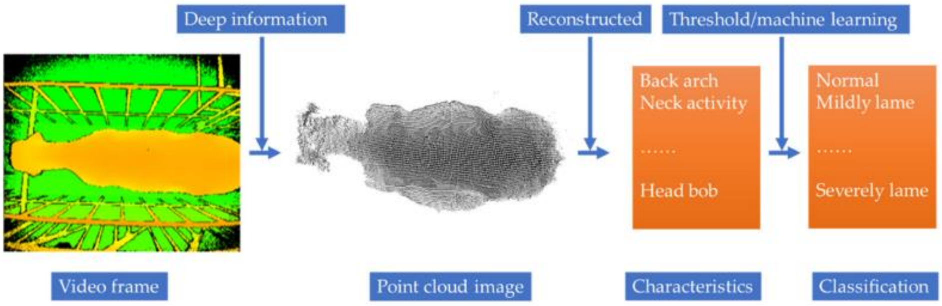

Figure 13 The process of computer vision and lameness scoring with a 3D camera from Kang et al. (2021).

One example of using cameras to score lameness is the measurement of the curve of the animal's back (Van Hertem et al., 2014; Viazzi et al., 2014a; Van Hertem et al., 2018; Kang et al., 2021). Van Hertem et al. (2018) have studied this application in a practical situation on a commercial dairy farm. Upon leaving the milking parlour, a video recording was made of the cow in a corridor with a 3D camera. The curve of the cow's back was measured to score lameness. This automatic scoring could only be achieved for half of the images. This practical study revealed that a constant calm flow of animals was required for a properly functioning system. Implementing a computer vision system that proved successful in a study setting a commercial conditions, such as on the farm, proves to be a challenge. Problems are often identified with the rapid flow of animals, capturing multiple animals simultaneously, animals positioned in front of the camera in the wrong place, animals stopping or running. In these cases, the images cannot be analysed (Van Hertem et al., 2018; Kang et al., 2021). In the trial design, the animals will walk in front of the camera calmly one by one, however, this is not always the case under conditions in the field, including at the slaughterhouse.

A thermal infrared camera is able to measure the temperature of the claws, with inflamed claws presenting with a higher temperature. The image, however, must be captured at short range (Kang et al., 2021). Making close-up images of the claw of the animal is not easily feasible in practice at the slaughterhouse, in addition to which lameness is not only caused by claw inflammations, but may, for example, also be caused by bone fractures or inflammation in places other than the claw.

4.1.4. Movement of pigs

In Denmark, Gronskyte et al. (2015;2016) captured the movements of pigs on video during the unloading process at a commercial slaughterhouse and subsequently analysed the recording using a statistical analysis or optical flow, working with the hypothesis that stationary animals indicate an animal with an injury or an obstacle. Animals moving too fast can likewise be an indicator of stress, as the animals may be agitated by external factors. This does not require identification for individual animals. The study conducted by Gronskyte et al. (2015) investigated the use of camera during the unloading of animals, in which attempts were made to classify the movement of pigs. Colour correction of the images was required due to soiling of the pigs and the dark background. The study showed that it is possible to detect movement on video images by means of so-called modified angular histogram analysis (MAH).

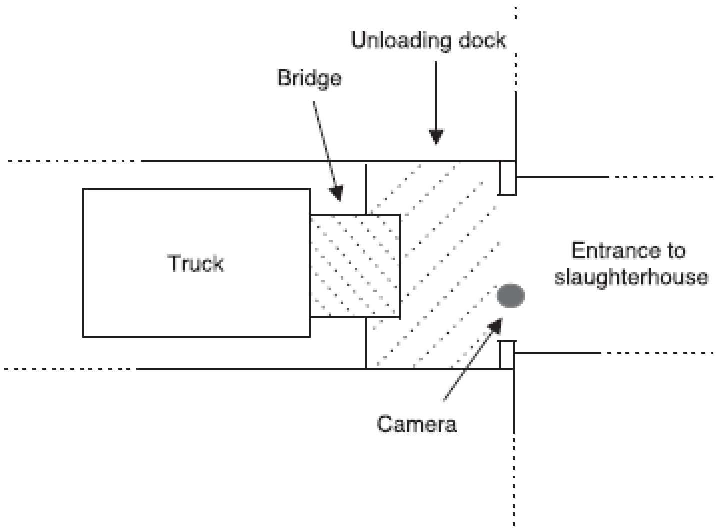

Figure 14 Camera setup during unloading of the animals at the slaughterhouse in the study conducted by Gronskyte et al. (2015).

The study conducted by Gronskyte et al. (2016) also examined the possibilities of identifying a stationary pig in this setting using modified angular histograms (MAHs). Please see figure 15 for the test procedure used. The MAH of a stationary pig is below the 25 -75 percentile of moving pigs, please see figure 16. This method can also be used to identify pigs that move too fast or too slow.

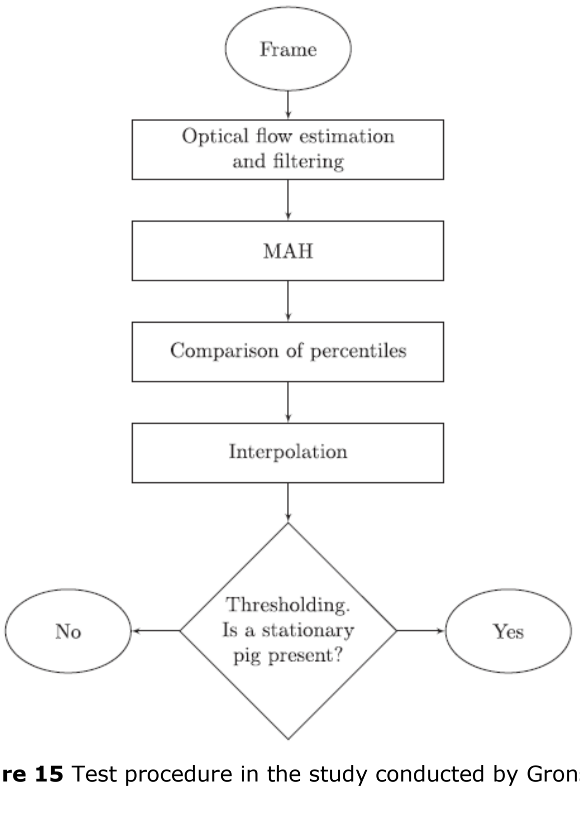

Figure 15 Test procedure in the study conducted by Gronskyte et al. (2016).

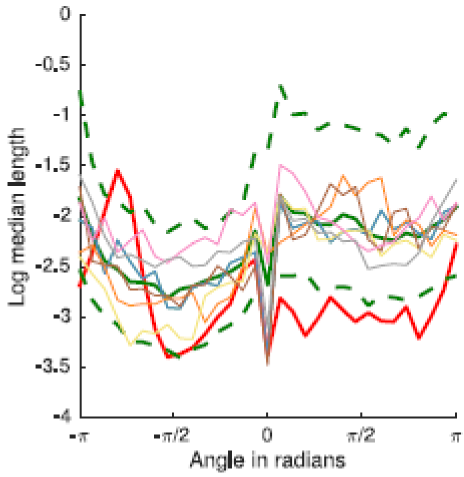

Figure 16 From Gronskyte et al. (2016), MAH of moving pigs: blue, orange, yellow, brown, pink and grey line. The median (green line) 25 and 75 percentile of moving pigs (broken green line) and the stationary pig (red line).

A camera system combined with AI was put into use at three Vion pig slaughterhouses in the Netherlands at the end of 2020. This software system involves the creation of an alert list for the camera images with abnormal patterns, such as stationary animals. This alert list is then used by the Animal Welfare Officer in the evaluation of the processes (BeterLeven, 2021a; Dierenbescherming, 2021). This system has not yet been externally validated.

The Dutch Society for the Protection of Animals intends to make this software system mandatory at slaughterhouses where cattle, calves, pigs and poultry are slaughtered according to the Better Life (Beter Leven) quality label concept. This system has yet to be developed for cattle and poultry (BeterLeven, 2021c;2021d;2021b). Vion have also indicated that they wish to install this system in all their slaughterhouses for pigs and cattle (Vion, 2021).

4.1.5. Aggressive behaviour in pigs

There are several examples of the use of video images to automatically detect aggressive behaviour in pigs. For example in the studies conducted by Viazzi et al. (2014b), Oczak et al. (2014), Nasirahmadi et al. (2016), Lee et al. (2016) and Chen et al. (2019). In all five studies, video recordings were made from the top of the pen. The first three studies use a 2D camera, while the studies of Lee et al. (2016) and Chen et al. (2019) use a 3D camera. In each of these studies, images of aggressive behaviour (such as head butting, biting or chasing) were manually labelled by experts to train the algorithm. Nasirahmadi et al. (2016) identified the pigs using an ellipse fitting algorithm and calculated the various axes of the ellipse (the Euclidian distance between 2 points). Whenever a pig mounts another pig, an abnormal ellipse is formed, allowing mounting behaviour to be identified automatically with the help of an algorithm. Please see the figure below for examples.

Figure 17 Pigs mounting one another yields an abnormal ellipse shape. When a pig is mounted from behind, the ellipse is enlarged (left-hand image) and the ellipse similarly is enlarged when a pig is mounted from the side (right-hand image) from Nasirahmadi et al. (2016).

All of these studies presented a high degree of accuracy (89-99.2%), sensitivity (86.8-98.2%) and specificity (88.6-96.7%). These results provide opportunities for the automatic detection of aggressive behaviour in pigs in the waiting pen at the slaughterhouse.

4.1.6. Sound analysis and vocalisations as a sign of fear and stress

Relatively simple microphones can be used to record audio, which can then be analysed using a computer. The advantage of sound analysis is that it gives the animals 'a voice', so to speak (Benjamin & Yik, 2019). The vocalisations are related to different emotions and therefore can tell us something about the wellbeing of the animal (Støier et al., 2011).

Chickens have different types of vocalisations that signify frustration, fear and stress, such as 'gakel' calls, alarm or squawk calls. Du et al. (2020) used these vocalisations to detect heat stress in laying hens. A sensor was used to measure temperature and humidity and a microphone was used to record the sound in the housing unit. Part of the data was used as a training set and vocalisations were scored manually. The algorithm was then trained using classification by support vector machines (SVM). Please see figure 18 for the process. The applied technology made is possible to automatically distinguish the distinct vocalisations (sensitivity of 95.1%). In addition, the researchers found a significant correlation between squawk calls and the THI (temperature humidity index) (r=0.60). The animals produced more squawk calls in the danger zone (THI 76-81) or emergency zone (THI > 81).

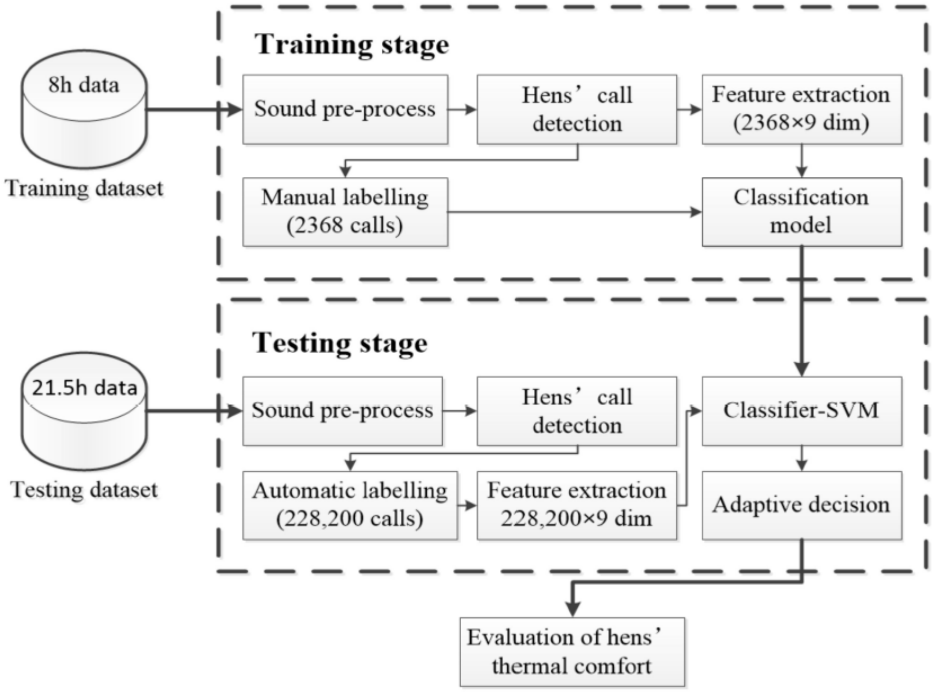

Figure 18 Flowchart for the automatic detection of vocalisations by laying hens in the study conducted by Du et al. (2020).

Pigs similarly expressed experiencing stress through vocalisations, such as squealing. In the study conducted by Schön et al. (2001), researchers were able to distinguish between stress vocalisations (squealing) and other sounds such as background noise and other vocalisations. This was fleshed out further in a subsequent study by Schön et al. (2004), through the application of the STREMODO system (STRess MOnitor and DOcumentation unit) at a commercial pig farm. Vandermeulen et al. (2015) use a different method, namely classification, which also takes into account the different characteristics of the squeals, such as duration, frequency and volume, and they were able to adapt the threshold value to the situation. Squealing due to competition at feeding time is less likely to be related to a highly stressful situation than at any other time. The sensitivity (71.8%) and specificity (91.4%) in this study were, however, lower than for the STREMODO method (99.3% sensitivity and 98.6% specificity).

In Denmark, Støier et al. (2011) have measured vocalisations in the waiting pen at the slaughterhouse. The excerpts were analysed manually and nine distinct vocalisations, such as grunting or squealing, could be isolated by the researchers. However, the study did not yet include automatic detection.

Briefer et al. (2022)have recorded vocalizations of pigs under different conditions (farm, during castration and at the slaughterhouse). Measurements were taken at the slaughterhouse, among other things, during driving up and when entering the restrainer. The developed AI model can distinguish between vocalisations related to positive and negative emotions on the basis of frequency (Hz), amplitude and duration of the vocalisations.

da Silva et al. (2019) measured the vocalisations of piglets under stressful conditions (cold, heat, pain, hunger and thirst) with a microphone and software was developed using algorithms that can predict the type of stress based on vocalisations. This involved examining both the intensity (decibels) and the duration of the vocalisation. There was a high degree of accuracy (98%) for pain: vocalisations following pain are higher in intensity and of a longer duration than vocalisations due to hunger, thirst, heat or cold. Please see the figure below.

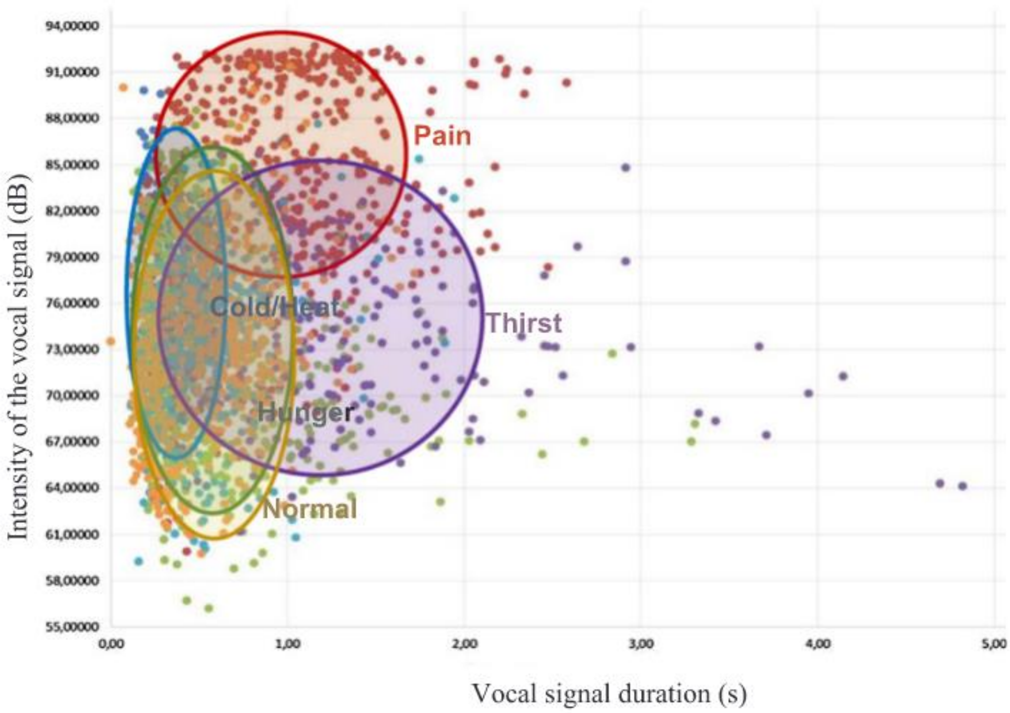

Figure 19 Intensity (dB) and duration (seconds) of vocalisations in piglets following pain, cold, heat, hunger and thirst and under normal conditions. From da Silva et al. (2019).

These studies show that background noise is not a problem on livestock farms when automatically detecting vocalisations. This also appears to be practicable at the slaughterhouse. Vocalisations caused by pain can be distinguished from other vocalisations based on their intensity and duration, although there continues to be overlap with other vocalisations. Sound analysis shows that the animal is experiencing stress and/or pain, but does not identify the cause of this stress and/or pain. This will have to be investigated further, for example, by reviewing the camera images.

In the various studies, vocalisations were measured in the housing unit or waiting pen, however, vocalisations should also be able to be measured during the stunning and killing of the animals. In this way, stress and signs of awareness can be captured by animals vocalising.

4.1.7. Measuring temperature using infrared

Infrared technology allows the skin temperature of an animal to be measured. The technique is based on the fact that any object will emit infrared radiation of a certain wavelength based on its temperature – this radiation can then be measured (Sellier et al., 2014; McManus et al., 2016; Benjamin & Yik, 2019). There are two types of commercially available infrared systems to measure temperature in animals: an infrared thermometer and thermal cameras.

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An infrared thermometer will measure the temperature of a specific point, whereas a thermal camera will measure a large number of points across a large area in order to generate a thermogram (Sellier et al., 2014). Thermal imaging allows the computer to convert the radiant heat into a colour image (please see the image below for an example) (Sellier et al., 2014; Benjamin & Yik, 2019). The advantage of this technique is that there is no need for direct contact with the animals, it causes less stress and takes less time (Petry et al., 2017; Zhang et al., 2019; Farrar et al., 2020). This provides opportunities for application at the slaughterhouse.

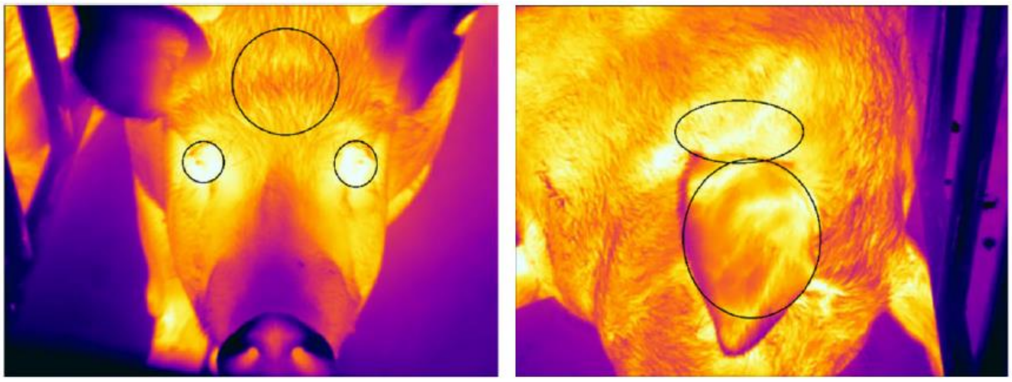

Figure 20 Infrared thermal images of pigs from the study conducted by Feng et al. (2019). The circles indicate the forehead, eyes, base of the ear and ear of the pig.

The reviews conducted by Sellier et al. (2014) and McManus et al. (2016) show that dozens of studies have been conducted in which infrared cameras have been used to measure skin temperature in animals. In most studies, the temperature of the same animal was measured on several occasions and changes in temperature were examined in order to study the effect, for example, of pain or stress on skin temperature, to detect disease or to obtain information regarding the animal's reproductive status or metabolism. As an example, the study conducted by Schaefer et al. (2012) measured the eye temperature of calves suffering from respiratory problems being on average higher over a period of 3 weeks than in calves without respiratory problems. These types of studies, looking at temperature differences in the same animal at different times, do not provide points of departure for the use of infrared systems to measure temperature in animals at the slaughterhouse that are immediately applicable.

At the slaughterhouse, the body temperature of an animal is a relevant parameter. The body temperature of an animal is related to the animal's health, nutrition, reproductive status, activity and stress response and any abnormal body temperature may be a sign of illness or thermal stress. Fever is a sign that the animal is sick. The classical method of measuring temperature in animals is taking its internal body temperature by way of a rectal measurement. The skin temperature is measured with infrared technology. Skin temperature is not automatically equal to body temperature. External factors have a significant impact on the reliability of infrared technology to measure body temperature (Feng et al., 2019; Farrar et al., 2020; Gómez et al., 2021). An animal's skin temperature depends on the environmental conditions (such as ambient temperature, humidity levels and air currents), the blood supply and body temperature (core temperature) of the animal. There are major differences in body temperature between the various body parts (please also see figure 20). In adult pigs, the fat layer provides insulation, which means that the skin will not accurately reflect the animal's body temperature. Any areas without fat or hair to provide insulation, such as the ears, better reflect the body temperature – these spots are also referred to as 'thermal windows' (Sellier et al., 2014; Benjamin & Yik, 2019; Zhang et al., 2019). In order to determine fever in animals, it is therefore vital that the measured skin temperature accurately correlates with the internal body temperature.

Petry et al. (2017) have compared various methods of measuring temperature in 23 sows with an average weight of 30 kg following infection with *Escherichia coli*, using rectal measurement, using an orally placed digital temperature sensor (internal body temperature) and with infrared images of the ear and eye using a thermal camera. Several images were captured of the eye and ear at a distance of 50 centimetres. There was a high correlation between rectal temperature, internal body temperature and eye temperature ($r > 0.96$), with a moderate correlation between the base of the ear and rectal temperature ($r = 0.57$) and a low correlation with the middle of the ear and tip of the ear ($r = 0.28$ and $r = 0.02$) (Petry et al., 2017).

Farrar et al. (2020) also compared the measurement of temperature using infrared technology and rectal temperature in 26 healthy pigs under sedation, aged 12-15 weeks old and weighing 13-20 kg. Photos of the eye and neck were taken at a distance of 60 to 81 centimetres. The correlation between rectal temperature and neck or eye temperature was weak ($r = 0.43$ and $r = 0.36$). At lower body temperatures, infrared technology underestimates the temperature and at higher body temperatures infrared technology provides an overestimation.

Feng et al. (2019) compared the rectal temperatures of 99 adult sows with the skin temperature of various body parts using infrared thermal imaging. This was done with the intention of predicting the rectal temperature on the basis the measured skin temperature using a model. The so-called thermal windows, i.e. eye and ear, yielded the best correlations. The researchers found a correlation of 0.68 and 0.67 respectively between rectal temperature and the maximum ear temperature and eye temperature. The researchers then developed a model that is able to predict rectal temperature based on parameters measured using infrared technology. The simplified model that was developed had a root-mean-square error for prediction (RMSEP) of 0.35 (the closer to 0, the better).

These three studies are examples of the fact that the results of the study when comparing infrared technology and rectal measurement of temperature in pigs are not consistent. Farrar et al. (2020) also highlight the fact that there is a highly significant degree of variation in the results of published studies. In addition, the first two studies referred to were conducted in young pigs. Young animals have a more uniform skin temperature than older and larger pigs (which are present at the slaughterhouse) (Farrar et al., 2020).

The study conducted by Salles et al. (2016) similarly did not find a good correlation between rectal temperature and the temperature of various body parts measured using infrared technology ($r = 0.25 – 0.32$).

In their study, Lu et al. (2018) did show that it is possible to automatically measure the ear temperature of pigs using thermal infrared cameras and algorithms. The system automatically detects the ears of the piglets and thus determines the temperature of the ears. This shows that it is technically possible to measure the ear temperature of pigs automatically using thermal infrared cameras. However, the question remains whether the ear temperature is a reliable indication of the internal body temperature in pigs and can therefore be used to automatically detect pigs with a fever at the slaughterhouse.

In addition, measurements obtained from infrared thermometers and cameras are affected by dust, local temperature and humidity (Sellier et al., 2014; McManus et al., 2016; Zhang et al., 2019). These conditions are relevant at the slaughterhouse.

Based on these findings, it can be concluded that there have been many different studies using infrared cameras to measure skin temperature in animals and a number of studies into the correlation between body temperature measured using infrared technology and body temperature. There is a (moderate) correlation between the thermal windows such as ear and eye temperature and the internal body temperature. These temperatures, however, do not correspond directly, which is why a predictive model is needed to calculate the internal body temperature, as took place in the study conducted by Feng et al. (2019). However, validated and commercially available systems have not yet been developed. Infrared technology may be able to be applied, however, this element is currently still under development.

4.2. Abnormal image of the carcass

Certain animal-based measures that provide information about welfare at the farm are easier to measure at the slaughterhouse, for example, because they only become visible during a post mortem inspection, with abnormalities presenting on the carcass, such as abnormalities in the organs. This section will discuss a number of examples of image analysis of carcasses at the slaughterhouse.

4.2.1. Footpad lesions in poultry

A number of systems are commercially available for scoring the footpad lesions in broilers, such as the system from Meyn or CLK GmbH (Meyn Food Processing Technology B.V, 2018; CLK GmbH, 2022a). Under the Animal Keepers Decree (Besluit houders van dieren), broiler farmers with a stocking density in category 3 (more than 39 kg/m² up to 42 kg/m²) must maintain records of[12] footpad lesion scores. At the slaughterhouse, this is done by a certified inspector (per flock, 100 feet per housing unit) or by a camera system (RVO.nl, 2020). For the monitoring of footpad lesions, using a digital measuring system, requirements are imposed in the Animal Keepers Regulations[13]:

This automatic measurement of footpad lesions is an example of an application of automatic

Animal Keepers Regulations (Regeling houders van dieren)
Article 7b.5. Additional standards for maintaining an occupation density of more than 39 kg/m² but not more than 42 kg/m²

7 The digital measuring system as intended in paragraph 3(a)(2°) satisfies the following requirements:

a. the system generates a reliable distribution of footpad lesions in the class referred to in paragraph 2, and of the results of the measurement according to the formula referred to in paragraph 4(b);
b. to ensure a reliable distribution, the system can be set to assess the feet of flocks processed subject to high temperature scalding and flocks processed subject to low temperature scalding;
c. the system can be set in such a way that the assessment of each flock is carried out individually;
d. the data as intended in part a must be generated at least once a day;
e. the images of the assessed flocks can be stored.

Appendix 4. Protocol for the monitoring of footpad lesions on broilers at slaughterhouses using a digital measuring system as intended in Article 6.5(3)(a)(2°) of the Animal Keepers Regulation

1. A report must be available at the slaughterhouse by an independent knowledge institution or body which indicates that the digital measuring system operates in such a way that the scoring delivers a score that is equivalent to the score from a visual assessment conducted according to the score card. The report must contain a description by the knowledge institution or body of the way in which this was determined.
2. The camera system measures at least 70% of the feet of each flock.
3. The percentages per class and the final scores must be generated by the system at least once every working day, processed by the slaughterhouse and passed on to the poultry farmer.
4. The slaughterhouse must take measures to protect the digital measuring system and the software used against random changes.
5. The slaughterhouse must ensure that the system is maintained in such a way that it continues to function correctly. If the system demonstrates defects or faults, the slaughterhouse must report this to the supplier or manufacturer, and the affected poultry farmers.

scoring using a camera at the slaughterhouse, for an animal-based measures which is not

[12] Animal Keepers Decree (Besluit houders van dieren), BWBR0035217
[13] Animal Keepers Regulations (Regeling houders van dieren), BWBR0035248

related to welfare at the slaughterhouse. The footpad lesions, after all, are caused at the farm where the animal first experiences the welfare consequences.

Since 2013, the Meyn Footpad Inspection System (a video-imaging system for automatically assessing footpad lesions on broiler chickens at the slaughter line) has been an authorised method for the scoring of footpad lesions in broilers (Van Harn & De Jong, 2017). Roughly 95% of footpads can be scored using this system. Footpad lesions are scored on a scale of 0 (no lesions) to 2 (severe lesions). Due to the fact that the system scores all footpads, it provides a more accurate picture of footpad lesions in a flock of broilers than the random assessment conducted by an inspector. Manual inspection of a flock of 30,000 broilers will only involve the assessment of 0.33% of footpads (Van Harn & De Jong, 2017).

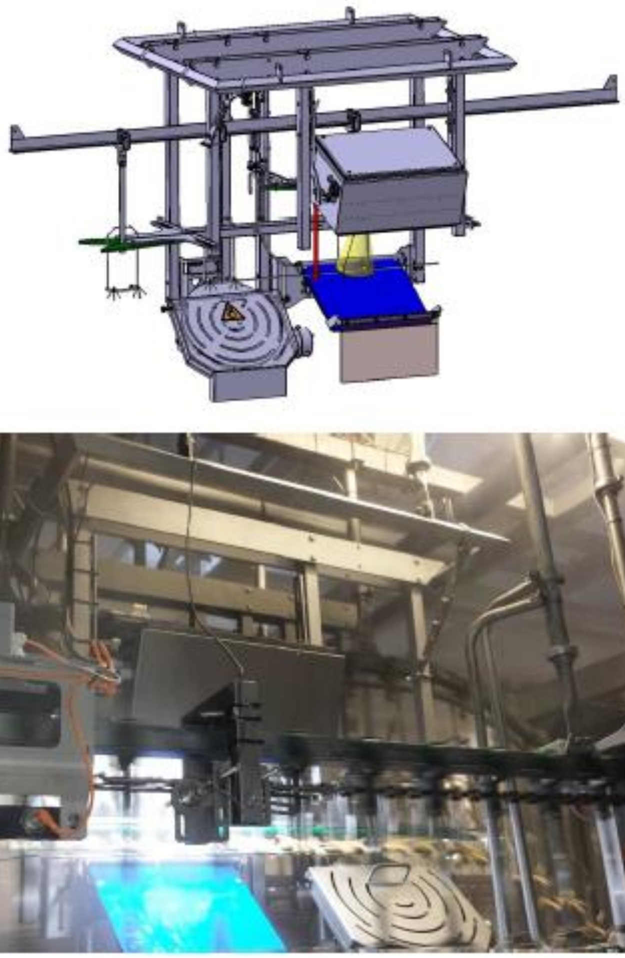

Figure 21 camera setup of the Meyn Footpad Inspection System at the slaughterhouse from Van Harn & De Jong (2017).

In 2017, Wageningen Livestock Research revalidated the system (external independent validation). The results of the camera measurements and the researcher's assessment were compared for a total of 18 flocks. In total, 400 pairs of feet were scored by the video system, with 100 right feet being scored by the researcher. For feet with a score of 0, the correlation (R^2) between the camera system and the researcher was 0.99, with a correlation of 0.40 for score of 1 and 0.95 for a score of 2. The camera slightly overestimates the low scores and underestimates the high scores. At flock level, there was a high degree of correlation (0.96). Based on this limited dataset, the researchers concluded that the camera system correlates accurately with the scores of the trained WLR inspector (Van Harn & De Jong, 2017).

At present, the system is only used in a number of slaughterhouses – possibly due to cost (Van Harn & De Jong, 2017). However, the slaughterhouses have all indicated that they wish to measure scores with a camera in due course (Pluimveeweb, 2018).

In Germany, the condition of the footpads has been assessed using camera-based monitoring systems in larger poultry slaughterhouses since 2011. This camera system assesses the footpads and classifies them into categories. The results are used as a quality parameter and are reported back to the farmer (Blömke et al., 2020; Louton et al., 2022).

Louton et al. (2022) investigated the system for scoring footpad lesions from CLK GmbH. Footpad lesions were placed on a scale from 0 (no lesion) to 3 (lesion deeper than 1 cm or multiple lesions). There was high sensitivity for a score of 0, 2 and 3 (0.87, 0.72 and 0.87 with the updated version of the system during the validation phase); for a score of 1, an insufficient (0.19). This is comparable to the results from the study by Van Harn & De Jong (2017) on the system from Meyn (Louton et al., 2022).

4.2.2. Commercially applied systems at poultry slaughterhouses

Various companies in the slaughterhouse industry have developed systems to automatically detect abnormalities in poultry carcasses in the context of product quality. This information, however, is also relevant in relation to animal welfare. One example is the foregoing Meyn Footpad Inspection System, however there are also systems which also indicate that they are able to detect broken wings, bruising and skin damage or weigh the carcass automatically (Jørgensen, 2018; Meyn Food Processing Technology B.V, 2019; BAADER Group, 2021; Foodmate B.V, 2021; Marel, 2021; CLK GmbH, 2022a). The detection rates or other information related to validation, however, are not publicly available, which is why no statement can be made regarding the reliability of the various systems.

4.2.3. Bleeding after sticking in pigs

After they are stunned, the pigs are stick to be bled and to be killed. If the sticking process is carried out incorrectly, the pigs may regain consciousness after having been stunned and go into the slaughter process conscious. A camera-based system was developed in Denmark to detect the correct bleeding of pigs: VisStick®. Immediately after the sticking of the pigs, a camera is mounted against an illuminated background. Two images are captured of each pig, which are analysed by the software to determine whether blood is flowing from the pig's snout. If there is no blood flow, an alarm is triggered (see figure 22). During the test phase, 5 tests were conducted with 250 pigs that had not been stick interspersed with 500 slaughtered pigs and it was found that 98-100% of pigs that had not been cut were detected. This system is used in Denmark on most pig slaughter lines as well as in several other Scandinavian slaughterhouses (Borggaard et al., 2011; Støier et al., 2016; DMRI, 2021).

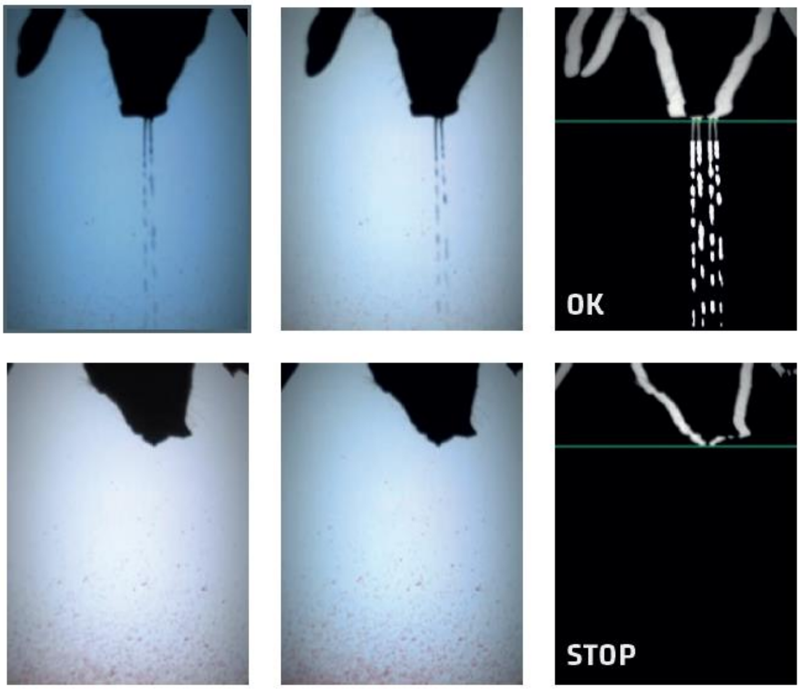

Figure 22 Detection of blood flowing from the snout in pigs using the VisStick system. Source: DMRI (2021).

The German company CLK GmbH has developed a system in which the volume of blood during bleeding is measured using a thermographic camera, combined with a warning system (CLK GmbH, 2022b). Vion indicates that it weighs the carcasses of the pigs at 4 pig slaughterhouses before and after bleeding (Vion, 2021).

A comparable technique could be applied to cattle slaughterhouses, but as far as we know it has not yet been developed.

4.2.4. Movement as a sign of consciousness

As part of the AI4Animals camera system, Deloitte also developed a system using a camera and AI to detect indicators of life and consciousness, following stunning and bleeding, in pigs and cattle (Deloitte, 2022). This system has not yet been externally validated and it is unknown whether the system is being used in the Netherlands and at how many slaughterhouses.

4.2.5. Ear and tail lesions in pigs

Another example of automatic scoring of welfare consequences at the slaughterhouse related to the livestock farm are ear and tail lesions in the study conducted by Blömke et al. (2020). At a slaughterhouse in Germany, a camera-based system was installed following the process of bleeding, scalding, depilation and singeing. A total of 5 images were taken of the entire carcass: one of the hind legs, one of the back, one of the head and two of the side. The slaughter number had been tattooed on the flank of the pigs for identification. The cameras were waterproof 2D cameras with 20 LED lamps to illuminate the carcasses. The cameras had been installed in front of a blue background.

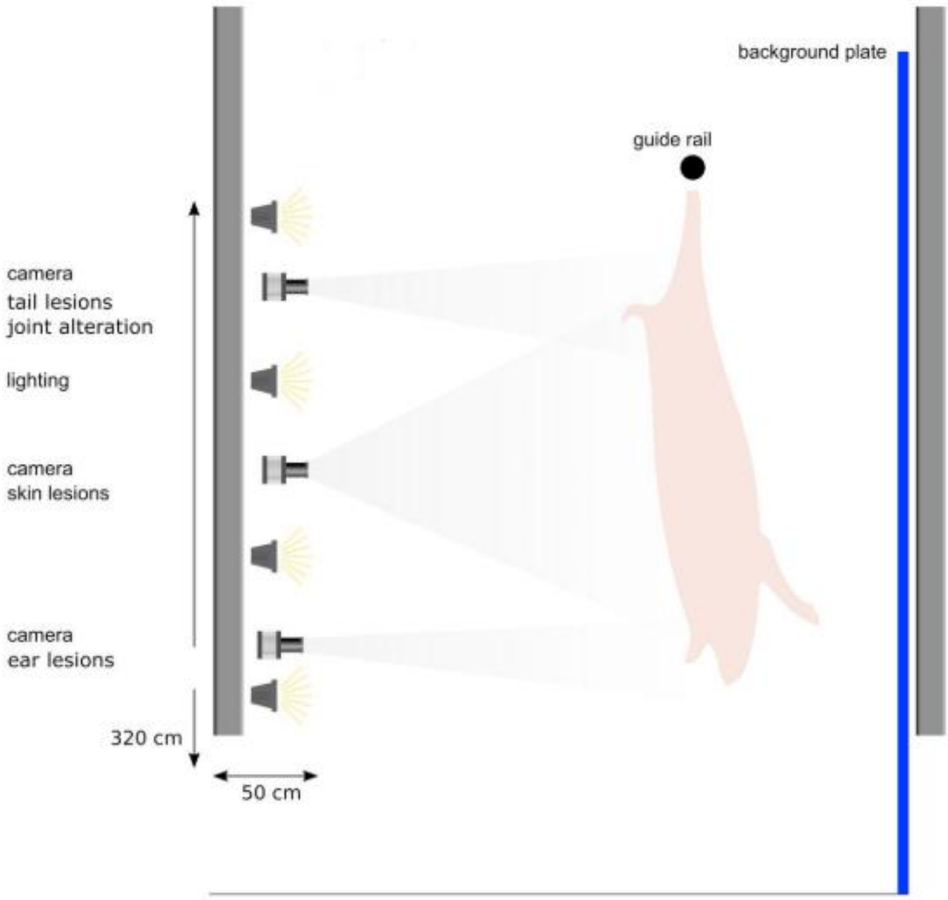

Figure 23 Camera setup in the study conducted by Blömke et al. (2020). Five images were captured per carcass.

The ears and the tails on the photographs were first identified using algorithms in the computer system, after which these parts were inspected for abnormalities. During the process, the algorithm was improved, for example, to exclude other ear abnormalities and colour variations of the tails. It proved impossible to take accurate photographs if, for example, the pig was shackled by one leg or the lens was foggy. The system was continuously improved through feedback from the veterinary observer and inspections of random photographs. Due to the high levels of humidity and cleaning activities, daily calibration and adjustment of the cameras was required. With regard to ear lesions, sensitivity was 77%, specificity was 96.5% and accuracy was 95.4%. For tail lesions, sensitivity was 77.8%, specificity was 99.7% and accuracy was 99.5%. The correlation (=reliability of the system) between the veterinary observer on the slaughter line and the camera was 0.62 for ear lesions and 0.55 for tail lesions. These low values may have been affected by the very short interval (8 seconds per pig) that the veterinary observer had to conduct an assessment. As a result of this study, the system has been validated and is now commercially available in Germany. The system records any thickening of the joints, decubitus of joints, necrosis of the tail and edge of the ear and tail length for each pig (CLK GmbH, 2022c).

Brünger et al. (2019) have likewise automatically scored tail lesions based on photographs at a slaughterhouse in Germany. Tail lesions were scored manually on a scale of 0 to 3; complete tail loss was similarly recorded. These scored images were then used to train a neural network. The results of the automatic assessment using the neural network were comparable to human observation (74% correspondence for the score of the tail lesions and 95% correspondence for tail loss).

4.2.6. Tail length in finishing pigs

The tail is an important means of communication for pigs. At present, many pigs' tails are still docked in the Netherlands to prevent damage and pain from tail biting. What part of the tail is docked varies for each company. The Vion slaughterhouse has stated that it has developed a system to measure tail length in pigs automatically using a vision system. The tail length of each individual pig is measured in order to gain insight into the performance of the pig farm. In this way, farms can be compared with one another with the aim of farms being able to learn from each and thereby raise pigs with longer tails (Vion, 2021). No additional public information is available regarding the system. It is therefore unknown to what extent this system is already being used in the Netherlands, how exactly the system works and how the system has been validated. The German CLK GmbH has also developed a system to measure tail length, which has been validated in the study of Blömke et al. (2020) (see paragraph 4.2.5.) (CLK GmbH, 2022c).

4.2.7. Pig cardiac and liver disorders

McKenna et al. (2020) have developed a system to automatically classify heart and liver disorders (pericarditis and white spots) in pigs, based on photographs taken at the slaughter line. The photographs were assessed by experts and subsequently, using machine learning, the system was trained to mark the region of the affected organ, after which the abnormalities were classified. The assessment of the system showed a good correlation with the assessment of the experts (0.81 – 0.94). The accuracy for the system's assessment of cardiac disorders was 0.96 and 0.89 for liver disorders.

4.2.8. Pulmonary disorders pigs

Trachtman et al. (2020) trained a system to score pleurisy in the lungs of pigs at the slaughterhouse automatically using deep learning. Photographs were taken of the thorax of the split carcasses with a smartphone at various slaughterhouses under varying conditions. Two veterinarians subsequently scored the degree of pleurisy on a scale of 0 to 4. The various parts and abnormalities of the thorax were likewise annotated manually on the images. The model was especially good at identifying healthy carcasses with a score of 1 (accuracy of 96%) and severe pleurisy with a score of 4 (92%). The accuracy was 70% and 84% respectively for scores of 2 and 3. This amounted to an average accuracy of 85.5% for the various scores for pleurisy. This system was developed by an Italian startup and is being developed further into a system that will be commercially available. In addition, work is ongoing on the recognition of other diseases in pigs (F4TLab, 2021).

4.2.9. Meat colour in veal calves

The colour of meat can be determined using a spectrophotometer or colorimeter (Vandoni & Sgoifo Rossi, 2009; Horcada et al., 2013). A colorimeter measures the L* (lightness), a* (red) and b* (yellow) (Hulsegge et al., 2001; Vandoni & Sgoifo Rossi, 2009). These meters are commercially available (Konica Minolta, 2021) and are used at the slaughterhouse in the Netherlands (BeterLeven, 2021c). In the Netherlands, the classification of meat in calves is carried out by assessors from Kiwa CBS (Kiwa, 2021).

In the Netherlands, the colour of veal is classified on a scale of 1 to 10 for white veal calves and on 11 to 13 for rosé veal calves (SBK, 2021).
Meat colour in beef is used to determine the quality and therefore the price of the carcass, but can equally be used to assess welfare (Vandoni & Sgoifo Rossi, 2009; Horcada et al., 2013). Consumers prefer white veal. In white veal calves, the animals' diet is kept low in iron in order to keep haemoglobin levels (Hb levels) in the calf low to ensure the characteristic white meat colour. However, at Hb levels lower than 4.5 mmol/l, animals suffer from (clinical) anaemia (Wageningen University & Research, 2018). By law, the diet of calves must contain a sufficient level iron to achieve average haemoglobin levels of at least 4.5 mmol/l[14]. This is an average per herd.

In their study in 1764 veal calves at 2 slaughterhouses in the Netherlands, Klont et al. (1999) showed that there is a relationship between Hb levels in the blood and the colour class scored by an experienced slaughterhouse assessor. Lower Hb levels yield a lower colour score (r=0.61). The correlation between L* measured by the colorimeter after 45 minutes post mortem and Hb levels was -0.60 and -0.73 for the colour class. In this study, colour classes 2 and 3 had average Hb levels below 4.5 mmol/L.

Several studies have looked at the application of a colorimeter to determine the meat colour in veal calves at the studies under commercial conditions. The colour of the pectoralis major muscle or the rectus abdominis muscle were determined 45-60 minutes post mortem. Two studies used discriminant analysis based on the L* and a* value of the colorimeter in order to create a classification based on the colour classes. The third study created a model based on multiple stepwise regression to predict the colour score. In these studies, classification by meat colour using the colorimeter correlates to the classification made by an assessor to a degree of 50% to 79%, depending on the number of classes on the scale (Hulsegge et al., 2001; Vandoni & Sgoifo Rossi, 2009; Horcada et al., 2013). In addition, in the study of Hulsegge et al. (2001) the difference was one class at 41.3%. Based on these studies, it can be concluded that determining the Hb levels based on meat colour measured with a colorimeter does not provide an accurate reflection, but does provide an indication.

4.3. Summary of findings for animal-based measures assessed using sensor technology

4.3.1. Animal-based measures assessed in live animals

The most cited examples of sensor technology combined with AI related to live animals are measurements conducted in groups of animals. Measurements conducted in individual animals, such as automated lameness scoring, are often not practically feasible at the slaughterhouse. The possibilities for automated measurement of animal-based measures using sensor technology in live animals at the slaughterhouse therefore lie primarily in measurements conducted in groups of animals. Abnormalities in behaviour in the waiting pen or during unloading of the animals can be recorded using a camera, which can then be combined with audio analyses to detect vocalisations as signs of stress.

More research is needed into the application of infrared technology for the detection of animals with fever at the slaughterhouse.

[14] Animal Keepers Decree, BWBR0035217

4.3.2. Animal-based measures assessed on the carcass

Sensor technology combined with AI also provides opportunities for measurements carried out on the carcass. The examples of the automatic scoring of abnormalities on the carcass, such as footpad, tail and ear lesions and pulmonary and cardiac disorders show that automated scoring based on image analysis can be applied at the slaughterhouse. These systems are already commercially available for poultry (validation, however, unknown), as are systems for pigs to recognise bleeding, identify tail and ear lesions or tail length. This information obtained at the slaughterhouse also provides insight into the prevalence of various welfare consequences at the farm or during transport (e.g. wing fractures).

4.3.3. Short and medium term opportunities

Forms of sensor technology combined with AI that provide opportunities in the short term consist of systems that studies have proved to be applicable in practice at the slaughterhouse and/or are commercially available. In the short term, the potential lies in the area of the welfare of poultry and pigs, but currently primarily presents opportunities for the slaughterhouses themselves. Sensor technology combined with AI can be used to monitor animal welfare and, where necessary, to implement improvements or to provide the farmer with feedback. Examples include abnormal movement in pigs during unloading, tail length and correct bleeding in pigs and abnormalities in the carcasses of poultry and pigs such as pulmonary disorders, various types of lesions or wing fractures.

The forms of sensor technology combined with AI that offer potential in the medium term are the systems which studies have shown allow one or more animal-based measures to be assessed using sensor technology, but which have not yet be implemented at the slaughterhouse (for this animal species). More development is required as well as independent external validation of both the system and the animal-based measures assessed. Research can be assigned to knowledge institutes regarding these subjects. These knowledge institutes will be able to carry out studies at the slaughterhouse. Examples include carcass abnormalities in cattle, abnormal behaviour during the unloading of cattle, vocalisations as signs of pain and stress during the slaughter process and automatic detection of heat stress and aggressive behaviour in pigs.

Table 2 provides a breakdown of the possibilities in the short and medium term.

Table 2 Opportunities for the measurement of animal welfare using sensor technology combined with AI at the slaughterhouse in the short and medium term

Technique	Measurement	Measuring point	Animal species	Welfare consequence	Info regarding phase
Short term					
Image analysis	Abnormal movement	Unloading animals	Pigs	Roughhandling of animals	Transport/ Slaughter-house
	Body condition score	Waiting area	Pigs and cattle	Health	Farm
	Correct bleeding	After sticking	Pigs	Conscious for slaughter process	Slaughter-house
	Carcass abnormalities (e.g. pulmonary disorders)	PM inspection	Pigs	Health	Farm
	Docked tails	PM inspection	Pigs	Management procedures - docking	Farm
	Carcass abnormalities (e.g. breast irritations, footpad lesions)	PM inspection	Poultry	Limitation of natural behaviour	Farm
	Carcass abnormalities (e.g. wing fractures, bruising)	PM inspection	Poultry	Health	Transport
Medium term					
Image analysis	Abnormal movement	Unloading animals	Cattle	Rough handling of animals	Transport/ Slaughter-house
	Lying behaviour	Waiting pen	Pigs	Heat stress	Slaughter-house
	Aggressive behaviour	Waiting pen	Pigs	Fear, pain, stress, injury	Slaughter-house
	Correct bleeding	After sticking	Cattle	Conscious for slaughter process	Slaughter-house

	Carcass abnormalities (e.g. pulmonary disorders)	PM inspection	Cattle	Health	Farm
	Carcass abnormalities (e.g. bruising)	PM inspection	Pigs and cattle	Handling during transport and unsuitable transportation	Transport
Sound analysis	Vocalisations	Waiting pen	Poultry	Heat stress	Slaughter-house
	Vocalisations	Slaughter	Poultry, pigs, cattle	Pain and stress	Slaughter-house

5. Use of sensor technology at slaughterhouses by the NVWA

For the NVWA, sensor technology at the slaughterhouse in relation to animal welfare can be used for a variety of purposes:

- Enforcement
- Monitoring animal welfare risks
- Efficiency (time savings)

Determining the prevalence of the welfare consequences and exposure to hazards for the purpose of risk assessment requires access to various data sources. A valuable source can be the data collected at the slaughterhouses by means of sensor technology. Data from the already commercially available and present systems in the slaughterhouses could be used (anonymously) to represent the prevalence of various welfare consequences such as broken wings, bruises and skin lesions in poultry.

The purpose of the motion[15] of February 2020 was to enable remote camera-based monitoring (by the NVWA) as part of (a) more (cost-)effective and efficient supervision at slaughterhouses. In the first few years, sensor technology will not yet be able to optimally contribute to making the NVWA's supervision more effective and efficient for several reasons. There are various key aspects that govern the use of data obtained at slaughterhouses using sensor technology and enforcement by the NVWA:

1. Legal basis for the application of sensor technology at slaughterhouses and the use of data
2. Impact (how significant is the welfare risk measured)
3. Enforceability (is there a standard to enforce in relation to the abnormality)
4. Validation

These points will be discussed in the following sections. The opportunities for and limitations of sensor technology must, however, also be taken into account in this application – please see Chapter 6.

[15] House of Representatives, 2019-2020 session, 33 835, No. 153.

5.1. Legal basis for the application of sensor technology at slaughterhouses and use of data

At present, there is no legal basis for the use of camera monitoring and sensor technology at slaughterhouses and regular camera surveillance has been introduced at medium-sized and large slaughterhouses on a voluntary basis. If a slaughterhouse does not wish to cooperate, the NVWA will intensify the monitoring of animal welfare through physical monitoring ('additional permanent supervision of the live components') at the expense of the slaughterhouse(NVWA, 2021e). The Minister is currently working on a Bill for a legal requirement for camera monitoring and is also examining the opportunities for smart camera monitoring. The larger slaughterhouses also use the cameras themselves for quality assurance purposes and a number of slaughterhouses have implemented smart camera monitoring systems themselves[16]. The systems and images, however, are the property of the slaughterhouses and the NVWA currently has no resources to make these systems mandatory in slaughterhouses. The systems will therefore have to be implemented at the initiative of the slaughterhouses themselves. The NVWA currently relies on the cooperation of slaughterhouses (except in relation to footpad lesions scores) for the use of the data.

In addition, according to the European Controls Regulation (Regulation (EU) 2017/625)[17], official control in connection with meat production such as the AM and PM inspection and control on health and animal welfare must be conducted by an official veterinarian or under the supervision of the official veterinarian. Complete replacement of the official veterinarian by a combination of sensor technology and AI is therefore not permitted at present. If the criteria were to be satisfied, however, sensor technology combined with AI could, for example, become part of secondary supervision by the NVWA and/or part of an approved quality system. For poultry, EU Directive 2019/627 already offers possibilities: "*the competent authorities may decide that only a representative sample of poultry from each flock undergoes post-mortem inspection if: (a) food business operators have a system in place to the satisfaction of the official veterinarian, that allows the detection and the separation of birds with abnormalities, contamination or defects"* and in addition the slaughterhouse ensures correct compliance with the hygiene regulations and no serious deviations were discovered during the AM inspection[18]. In the case of a quality system, the owner of the quality system must itself submit the application for acceptance to the NVWA. The NVWA will then test whether the quality system satisfies the conditions and criteria (Ketenborging.nl, 2022; NVWA, 2022) Here, it is vital that the system should contribute to better safeguarding of animal welfare. The slaughterhouse

[16] Parliamentary Paper, House of Representatives, session 2020–2021, 28 286, No. 12171, Letter from the government; Outstanding motions and commitments following the two-minute debate on progress in improvements to the slaughter system

[17] REGULATION (EU) 2017/625 OF THE EUROPEAN PARLIAMENT AND THE COUNCIL of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products, amending Regulations (EC) No 999/2001, (EC) No 396/2005, (EC) No 1069/2009, (EC) No 1107/2009, (EU) No 1151/2012, (EU) No 652/2014, (EU) 2016/429 and (EU) 2016/2031 of the European Parliament and of the Council, Council Regulations (EC) No 1/2005 and (EC) No 1099/2009 and Council Directives 98/58/EC, 1999/74/EC, 2007/43/EC, 2008/119/EC and 2008/120/EC, and repealing Regulations (EC) No 854/2004 and (EC) No 882/2004 of the European Parliament and of the Council, Council Directives 89/608/EEC, 89/662/EEC, 90/425/EEC, 91/496/EEC, 96/23/EC, 96/93/EC and 97/78/EC and Council Decision 92/438/EEC (Official Controls Regulation), OJ L95, 7.4.2017, pp. 1–142.

[18] COMMISSION IMPLEMENTING REGULATION (EU) 2019/627 of 15 March 2019 laying down uniform practical arrangements for the performance of official controls on products of animal origin intended for human consumption in accordance with Regulation (EU) 2017/625 of the European Parliament and the Council, and amending Commission Regulation (EC) No 2074/2005 as regards official controls.

must prepare procedures indicating how findings from the system of sensor technology combined with AI are followed up. The NVWA will then ensure that this is carried out correctly.

5.2. Animal welfare risks at the slaughterhouse and sensor technology

As outlined in section 1.3.3., according to the findings of BuRO, most welfare consequences in the primary phase relate to 'good health' and to the presence of disease in particular. The measurement of carcass abnormalities using cameras at the slaughterhouse in poultry and pigs is an example of an implemented technology that can shed light on the occurrence of these welfare consequences. This may, for example, relate to pulmonary disorders in pigs, such as in the study conducted by Trachtman et al. (2020). The same technology can be used to record welfare consequences in poultry carcasses such as the indirect effects of limitation of the performance of species-specific behaviour. Examples of which include breast blisters, hock burn, footpad lesions and wing fractures. A large number of systems are already commercially available for poultry and a number of systems are likewise commercially available for pigs or have been applied in studies. Few technologies are available for cattle or have been the subject of studies into applications that correspond to the most critical welfare consequences.

Factors that play a major role in relation to risks during transport include a combination of rough handling of animals by (external) employees during the catching and loading process, insufficient precautions during transport and inadequate equipment of the means of transport. One type of technology that is able to identify these factors is the application whereby the movements of pigs are analysed during unloading, as took place in the studies by Gronskyte et al. (2015;2016) and takes place at the Vion slaughterhouses. Bruising and other types of damage that can arise a result of this handling can be detected on the carcass.

The Danish VisStick system, which detects bleeding, is another example an application used for the detection of serious welfare consequences as a result of 'slaughter' as a whole, such as inadequate slaughter facilities, inadequate killing procedures and failure to intervene in the event of incorrect use. In addition, sound analysis for vocalisations as a sign of stress, fear and pain, provides various starting points for technological applications. Opportunities also lie in the area of detection of movement after the stunning process, such as detecting muscle spasms, body movement or maintaining a specific position. Further research into these applications is required.

5.3. Enforcement

The NVWA can only enforce standards on welfare consequence if such statutory standards are place. Most of the rules and regulations in relation to animal welfare at the farm are set out in the Animals Act[19] and the underlying Animal Keepers Decree[20]. The Animals Act or the underlying regulations do not include national standards for specific rules and regulations regarding the transport of animals and the phase at the slaughterhouse (except for the killing

[19] Animals Act, BWBR0030250
[20] Animal Keepers Decree, BWBR0035217

of animals without prior stunning). The transport of animals falls under the Council Regulation (EC) No 1/2005[21] and Council Regulation (EC) 1099/2009[22] applies to the slaughterhouse.

5.3.1. Qualitative goal-oriented standards (open standards)

Many laws and regulations relating to animal welfare, however, consist of qualitative goal-oriented standards, also referred to as open standards (please also see the advisory report on the evaluation of the Animals Act by BuRO (2020b)).

Some examples:

- Animal Keepers Decree, Section 1.7(3): *'Any person keeping an animal shall ensure that an animal that appears sick or injured is given immediate and appropriate care.'*
- Article 3 of the Animal Transport Regulation (EC) 1/2005): *'No person shall transport animals or cause animals to be transported in a way likely to cause injury or undue suffering to them.'*
- Article 3 of the Council Regulation (EC) No 1099/2009 on the protection of animals at the time of killing: *'Animals shall be spared any avoidable pain, distress or suffering during their killing and related operations.'*

When developing sensor technology combined with AI, limit values must be established in order to be able to create a classification. Any deviation from the target value must be able to be identified. In the case of open standards, legal target values have not been established. For example, there are no legal standards that set out the number of vocalisations as sign of pain or distress that should be considered an avoidable form of pain, distress or suffering. Similarly, there are no legal standards for the maximum number of cases of pneumonia in pigs. Enforcement cannot take place pursuant to the value alone. With regard to enforcement of open standards, a supervising veterinarian and/or inspector must provide reasons substantiating why in this specific situation, based on the established facts, the open standard was violated. To allow for enforcement of open standards using sensor technology combined with AI, these standards will have to be fleshed out, for example, with a scientific basis and/or policy rule. Another option would be for any deviation from an established target value to be used as an indicator, with the supervising veterinarian subsequently assessing whether the situation constitutes a violation of the laws and regulations – as is currently the case in situations without sensor technology.

5.3.2. Quantitative goal-oriented standards (closed standards)

In the case of quantitative goal-oriented standards, a closed standard (such as a limit value) will be set out in the law.

5.3.2.1. Footpad lesion score

The standard for footpad lesions in broilers is an example of a quantitative goal-oriented standard in which sensor technology is combined with AI. Under the Animal Keepers Decree (Besluit Houders van dieren), broiler farmers with a stocking density in category 3 (more than 39 kg/m² up to 42 kg/m²) must maintain records of footpad lesion scores. Feet without

[21]Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97, OJ L 3, 5.1.2005, p. 1–44
[22]Regulation (EC) No 1099/2009 of the European Parliament and of the Council of 24 September 2009 on the protection of animals at the time of killing (text relevant to EEA), OJ L 303, 18.11.2009, p. 1–30

footpad lesions receive a score of 0, moderate footpad lesions receive a score of 1 and severe footpad lesions receive a score of 2. This is how the footpad lesions score per flock per housing unit is calculated, which will be between 0 and 200 points. The average score at the establishment must be below 80 points per calendar year. If the score is between 80 and 120 points, the farmer must draw up an improvement plan and submit the plan to RVO.nl. If the average score of the establishment exceeds 120 points, then the farmer must draw up an improvement plan, submit the plan and reduce the stocking density in the housing unit to a maximum of 39 kg/m² for the remainder of the calendar year. Scoring of footpad lesions takes place at the slaughterhouse and is conducted by a certified inspector (100 feet per flock, per housing unit) or by a camera-based system (RVO.nl, 2020). One example of this type of system is the Meyn Footpad Inspection System, which is already a legal authorised method for the scoring of footpad lesions in broilers (Van Harn & De Jong, 2017) (also see section 4.2.1.).

5.3.2.2. Conscious during killing process

Under Council Regulation (EC) No 1099/2009, animals may only be killed when they are unconscious and insensitive (with the exception of ritual slaughter). The animals must not present any signs of awareness, consciousness or sensitivity between the end of the stunning process and their death. Sensor technology combined with AI would be able to help detect mistakes in the killing process, such as is carried out by the detection of insufficient sticking in pigs by the Danish VisStick system.

5.3.3. <u>Enforcement standards</u>

In addition to the quantitative goal-oriented standards included in the laws and regulations, the NVWA has also drawn up a number of enforcement standards. These enforcement standards are laid down in working instructions and the intervention policy and are publicly available.
Some examples:

5.3.3.1. Catching-related injuries in poultry

Under the Animal Transport Regulation (EC) No 1/2005, transport may not cause injury and in the event of catching-related injuries in poultry exceeding 2%, the NVWA will take enforcement action. Catching-related injuries are injuries suffered during the capture of poultry, which are mostly evidenced by dark red to purple haemorrhages, sometimes in combination with broken wings or other bones. Catching-related injuries are determined by the supervising veterinarian in the 'ready to cook' department in an area with lots of light, with the plucked carcasses positioned for post mortem inspection in such a way that the breast side of the carcass (including the legs and wings) can be clearly inspected. To get a clear picture of the whole flock, counts are performed on at least two occasions, with each count taking at least two minutes. For example, this can be a count of 1/3 of the flock and a count of 2/3 of the flock. The percentage of catching-related injuries is calculated by taking the average of the two counts. To determine the percentage of catching-related injuries, only dark red to purple haemorrhages of at least 3 cm in size will be counted. These counts are carried out if the supervising veterinarian has identified reasons to do so or during a periodic inspection (NVWA, 2021d). At present, identification of catching-related injuries still takes place manually, however, there is potential in this area for the application of sensor technology combined with AI. The haemorrhages are visible on the carcass and several studies have shown that sensor technology combined with AI allows for carcass abnormalities to be detected. In addition, a number of systems are already commercially available (see section 4.2.2.).

5.3.3.2. Potentially poor animal welfare conditions at primary poultry establishments

The appendix to the working instructions K-PL-WLZ-WV-01 states that the supervising veterinarian will assess whether there 'may be poor animal welfare conditions' at the establishment of origin for all flocks being unloaded or loaded for slaughter and for all types of poultry. This therefore relates to both broilers of all stocking densities and other poultry such as ducks, laying hens and broilers from organic or free-range systems. A report of findings is drawn up if 50% of the inspected animals exhibit severe footpad lesions (score of 2), 50% of the inspected animals present with one or more forms of contact dermatitis, and/or a combination of the foregoing issues, with 50% of inspected animals exhibiting the abnormalities referred to, and/or due to the FCI (Food Chain Information) stating a mortality higher than 5% in broilers and meat ducks, higher than 10% in laying hens, higher than 15% in breeding stock, exceeding 10% in broiler turkeys, and this cannot be accounted for as a result of disease. The supervising veterinarian will manually assess 50 animals twice (NVWA, 2021c). A number of systems using sensor technology combined with AI to detect these abnormalities are already commercially available (see section 4.2.2.).

5.4. Validation

In order to be able to rely on the findings of sensor technology combined with AI, it is vital to the NVWA that the system should be properly validated, for example, by an independent third party: does the system measure what the system promises to measure? What is the system's accuracy, integrity and reliability and what is the situation regarding the comparability of the various systems and set against a gold standard (e.g. the current manual assessment used by veterinarians)? This is particularly important for use in enforcement contexts. In addition, issues such as the algorithms used being transparent and easy to explain play a key role. In addition to a valid system, the validity of the animal-based measures used in relation to animal welfare is crucial. In other words, does the system, in conjunction with the animal-based measure, provide information on animal welfare that is adequate and sufficiently reliable. Examples of externally validated systems are the Meyn Footpad Inspection System and the German system for ear- and tail lesions in pigs of CLK GmbH (Van Harn & De Jong, 2017; Blömke et al., 2020).

5.5. Future focus of BuRO on animal welfare and sensor technology in combination with AI

At present, BuRO is unable to obtain all the necessary information required for a thorough risk assessment. Too little data (both internal and external) is recorded on a transparent and structural basis. A full risk assessment requires information on the prevalence of the welfare consequences and exposure to the hazards/risk factors. This information is often not available. Sensor technology at the slaughterhouse may provide BuRO with the opportunity to collect data on animal welfare, allowing the welfare of animals of multiple establishments to be assessed, recorded and monitored in a single location. In this way, accurate insight can be gained into the animal welfare risks and benchmarks, for example, can be drawn up. In addition, sensor technology provides a range of options for the identification of serious welfare risks at the slaughterhouse.

Sensor technology combined with AI will be one of BuRO's key priorities for the coming years. BuRO's efforts on the subject of sensor technology combined with AI and animal welfare will in any case consist of the following areas of action:

1. Keeping up to date with any (European) initiatives and working groups regarding the application of sensor technology combined with AI at the slaughterhouse and getting involved where possible. RIBMINS[23], for example, is one of those initiatives.
2. Creating awareness and fostering collaboration within the NVWA regarding the opportunities for applications of sensor technology combined with AI in relation to animal welfare.
3. Identifying potential future applications (POCs: proof of concepts)
4. Seeking out collaborative partnerships with knowledge institutes and organisations for the development and application of sensor technology combined with AI at the slaughterhouse for the purpose of knowledge adoption and/or implementation of POCs.
5. Setting up a multi-year research programme for sensor technology combined with AI and animal welfare, with the aim of developing knowledge to be able to systematically use data from slaughterhouses, for example, for benchmarking and/or identifying the risks at the slaughterhouse, during transport or at the farm.

Based on the above, the following topics related to sensor technology combined with AI and animal welfare offer prospects for inclusion in BuRO's envisaged multi-year research programme:

Prevalence of key welfare consequences

The measurement of carcass abnormalities using cameras at the slaughterhouse is an example of an implemented technology that can shed light on the occurrence of these welfare consequences related to animal welfare at the farm. Examples include pulmonary disorders in pigs and breast blisters, hock burn, footpad lesions and wing fractures in poultry.

Setting a benchmark

In conjunction with the prevalence of the welfare consequence, the same information can be used to establish a benchmark. Information on the occurrence of certain carcass abnormalities (such as footpad lesions) can be used to compare farms, draw comparisons with the desired level of animal welfare or to monitor animal welfare over several years. The latter also offers to possibilities, for example, regarding the percentage of docked tails in pigs. In the Netherlands, an estimated 98% of pig tails are docked in the first week of life. At many farms, the risk of tail biting is high if tail docking does not take place. Routine tail docking has long been prohibited by law and pressure to ban tail docking altogether has increased in recent years. In addition, there are a number of concepts that successfully market pigs with intact tails. It is expected that an increasing percentage of pigs with undocked or less closely docked tails will be slaughtered in the coming years. At present, Wageningen Livestock Research is carrying out a baseline measurement on behalf of BuRO. The percentage of docked tails is assessed manually on the basis of photographs. In future, a similar type of technology could be used for this type of monitoring as was the case in the studies conducted by Brünger et al. (2019) and Blömke et al. (2020), which focused on tail lesions. The Vion slaughterhouse has

[23] RIBMINS (Risk-based meat inspection and integrated meat safety assurance) is a European network that serves to combine and strengthen European research in the field of modern meat inspection systems. The network consists of several Working Groups. Working Group 4 studies a number of specific objectives, including the implementation of camera-based technology in meat inspection https://ribmins.com/

indicated that it has already developed a system to measure tail length in pigs automatically (Vion, 2021) – this system has not yet been externally validated.

Automatic measurement of animal-based measures for heat stress
In 2020, BuRO issued an advice on the transport of finishing pigs and broilers at (extremely) high temperatures (BuRO, 2020a). BuRO concluded that no robust indicators for heat stress could be found in the literature, except for death rate on arrival. In addition to tightening up of the National Plan for Livestock Transportation (Nationaal Plan voor veetransport), BuRO therefore recommended a more complete and integrated use of (animal) indicators to record animal welfare in order to obtain more accurate insight and for the benchmarking of transporters and slaughterhouses. The following recommendation was subsequently issued: *'A more comprehensive and more integrated use of (animal) indicators should be pursued to determine the welfare of animals (especially pigs and broilers) during transport, with any observed data being recorded from temperatures > 25ºC.'* Sensor technology provides an opportunity for the automatic measurement of (animal) indicators related to heat stress and for the establishment of a benchmark. Animal-based measures and environmental indicators must be combined. Temperature can be measured as an environmental indicator and vocalisations as an animal-based measure of stress. Du et al. (2020), for example, have already used automatic measurement of vocalisations to detect heat stress in laying hens. Thermal imaging likewise provides opportunities for heat stress on arrival at the slaughterhouse to be detected (EFSA, 2011; Koltes et al., 2018) is warrants further exploration.

Vocalisations as a sign of fear, pain and stress at the slaughterhouse to support supervision
Sound analysis for vocalisations as a sign of stress and pain provides starting points for the detection of instances of fear, pain and stress. In the various studies, vocalisations were measured in the housing unit or waiting pen, however, vocalisations should also be able to be measured during the stunning and killing of the animals.

Various studies have shown that background noises on livestock farms are not a problem when automatically detecting vocalisations. This also appears to be practicable at the slaughterhouse, however, it is unknown whether this is actually the case at the slaughterhouse and in areas other than the waiting pen. Vocalisations caused by pain can be distinguished from other vocalisations based on their intensity and duration, although there continues to be overlap with other vocalisations. Sound analysis shows that the animal is experiencing stress and/or pain, but does not identify the cause of this stress and/or pain. This will have to be investigated further, for example, by reviewing the camera images.
In this way, sound analysis can contribute to the NVWA's supervision. Vocalisations are a sign that 'something is wrong' and can therefore be signal for the situation to be investigated further, for example, by reviewing camera footage.

Signs of consciousness during the slaughter process
The Danish VisStick system, which detects bleeding, is another example of an application used for the detection of serious welfare consequences as a result of 'slaughter' as a whole, such as inadequate slaughter facilities, inadequate killing procedures and failure to intervene in the event of incorrect use. No directly practically applicable studies have as yet been conducted or technologies developed for other animal species, however, comparable applications could be achieved. There are technically other possibilities available for animal-based measures

related to signs of consciousness, such as in the form of motion detection, potentially combined with sound analysis aimed at vocalisations as a sign of pain, fear and stress. However, no specific research has yet been conducted in this regard. Therefore more research and development is required for this application.

All these issues will be able to be addressed in the research programme in the years to come. In addition to the use of sensor technology at the slaughterhouse, BuRO will also focus on the application of sensor technology at the farm and during transport to measure animal welfare. Opportunities similarly lie in the area of combining data obtained at the farm and information obtained at the slaughterhouse.

6. Opportunities and limitations of sensor technology

6.1. Opportunities

Sensor technology offers a variety of opportunities for the assessment of animal welfare at slaughterhouses.

1 Sensors make more constant and more accurate measurements than humans

Due to the high processing speed at the slaughterhouse, the setup of a slaughterhouse may make it difficult for assessors to visually inspect the animals or measure parameters such as heart rate or respiration on the animal (Wigham et al., 2018). Cameras can be mounted in a location that is difficult for people to reach. Cameras are also capable of capturing images at high speed, which can be analysed at a later stage (Farm Animal Welfare Committee, 2015) as well as record images day and night.

At the slaughterhouse, specific problems arise in relation to the identification of welfare consequences by humans in the case of poultry. Upon arrival, the animals are located in crates, which means that not all animals are clearly visible. Neither is there always enough light to properly assess the animals. In addition, due to the high speed of the slaughter line, less than one second is available to identify abnormalities in each carcass (Allain et al., 2018).

2 Sensors are relatively cheap and simple

Relatively simple and inexpensive cameras can be used to capture camera images (Rushen et al., 2012; Gronskyte et al., 2016; Nasirahmadi et al., 2017; Benjamin & Yik, 2019). The study conducted by Trachtman et al. (2020) even used smartphones to take photographs.

3 A sensor measures objectively and in a standardised manner

Using sensors and AI, data can be captured in a continuous and standardised manner compared to manual scoring by observers, which is very time consuming and may also lead to possible variation in scores between observers (Trachtman et al., 2020), meaning that the former allows for more uniform scoring (McKenna et al., 2020).

4 Combination of sensors or measurements possible

Capturing and analysing both audio and video recordings, for example, allows more reliable information to be obtained than from a single sensor (Nasirahmadi et al., 2017), for example, using a combination of video footage of aggressive behaviour and sound recordings of vocalisations.

Multiple analyses can also be conducted based on the images captured by a camera, for example, in relation to the distribution of the animals in the pen and detection of aggressive behaviour.

5 Captured data can be analysed (automatically)
A great deal of data is recorded using sensor technology, which can subsequently provide more information on the welfare of animals following analysis. This data may, for example, be used as feedback for livestock farmers or for epidemiological studies (Trachtman et al., 2020). This also provides opportunities for the NVWA in respect of data collection relating to welfare consequences. In addition, any findings of sensors made at the farm may be linked to the findings obtained at the slaughterhouse in order to gain even more information.

Any images can be stored and reviewed as needed. These images can be used as evidence of any abuses, during training courses or for inspection purposes (Farm Animal Welfare Committee, 2015).

6 No direct contact with animals or carcass required
Automatic measurement of indicators, such as lameness, does not require direct contact with the animals and likewise allows the welfare of smaller animals, such as poultry, to be measured (Rushen et al., 2012; Kang et al., 2021).

The various technologies also have potential in the area of PM inspections, given that there would no longer have to be any physical contact with or dissection of the carcass, reducing the risk of cross-contamination (McKenna et al., 2020).

7 Animal-based measures for groups of animals can be assessed
Due to the fact that any cameras or microphones would be installed within a given space and are not connected to an individual animal, this allows for the welfare of several animals to be assessed based on animal-based measures (Nasirahmadi et al., 2017).

8 No additional stressor
A camera or a microphone can easily be installed within a space and will therefore not cause any additional distraction, fear or stress, which the presence of humans may (Farm Animal Welfare Committee, 2015; Gronskyte et al., 2016).

9 Possible positive effect on conduct of slaughterhouse staff
Several studies have shown that the placement of cameras or the presence of auditors had a positive impact on the conduct of employees at these stations within the slaughterhouse (Wigham et al., 2018).

6.2. Limitations
In addition to opportunities, there are similarly limitations to the use of sensor technology at slaughterhouses:

1 Software can be expensive
The programmes used to analyse images may be expensive to purchase or to develop (Rushen et al., 2012).

2 Innovative solutions for data storage and processing required
Constant monitoring will mean storage of a large quantity of data, all of which would require a large amount of capacity. Constant monitoring with a 2D camera would yield 141 gigabytes of visual data per day, amounting to nearly 4 terabytes per month (Arulmozhi et al., 2021). This requires innovative solutions with regard to data storage. Also the protection and security of the stored data is an important point.

3 Development (algorithm training) requires extensive preparation
Developing a sufficiently reliable system requires a great deal of manual work to be carried out in preparation beforehand. Hundreds to thousands of images must be manually reviewed by experts to each the system to recognise any anomaly. In addition, the system must be (externally) validated.

4 Tailored approach required for individual sites
Many systems will have been developed at a test facility, such as a pilot farm, or by a university. The circumstances as well as type of animals, for example, will differ per location. The system must be validated for local conditions. This requires data in order to train the model (Arulmozhi et al., 2021).

5 No agreements on validation in the scientific community or within government yet
To date, no concrete commitments have been established nor any accepted methods for the validation of these systems (Herlin et al., 2021).

As yet, no government-wide agreements have been made regarding the quality and validation of algorithms, as recommended by the Algemene Rekenkamer (2021). In 2021, the European Commission submitted a proposal for an EU regulation in area of AI to the Member States[24].

6 Quality of the gold standard (validation of animal-based measures used)
The data can then be compared with a target value (gold standard) and, for example, flag whenever the data deviates from the target value (Rushen et al., 2012; Norton & Berckmans, 2018; Benjamin & Yik, 2019; Van Erp-van der Kooij & Rutter, 2020; Herlin et al., 2021). The animal-based measure used as a gold standard must be able to identify a specific welfare consequence, be repeatable and reliable (EFSA, 2012d;2012e). For a good system, not only must the algorithm be validated, but firstly also the animal-based measure used (Louton et al., 2022).

7 Sensor location, not everything can be recorded
The camera must be installed in the correct position in order to be able capture detailed images (Rushen et al., 2012). Due to the layout of the slaughterhouse, cameras cannot always be mounted in the desired location and even multiple cameras cannot capture images of the entire area (Gronskyte et al., 2016).

8 Disruption of recordings
Varying lighting conditions may cause problems when capturing images (Benjamin & Yik, 2019) or cameras maybe become dirty due to dust or due to a fly landing on the camera (Farm

[24] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL LAYING DOWN HARMONISED RULES ON ARTIFICIAL INTELLIGENCE (ARTIFICIAL INTELLIGENCE ACT) AND AMENDING CERTAIN UNION LEGISLATIVE ACTS COM/2021/206 final

Animal Welfare Committee, 2015; Nasirahmadi et al., 2015). Systems can fail due to a malfunction.

9 Sensor technology combined with AI measures a single thing

Many systems that have been developed only measure a single type of anomaly, namely the anomaly for which the system has been trained. Several technological systems are required in order to detect multiple aspects. Humans are able to detect and identify multiple anomalies (Arulmozhi et al., 2021). Therefore, at present, sensor technology combined with AI is unable to fully replace humans.

10 Sensor technology combined with AI does not establish standards

When developing sensor technology combined with AI, limit values must be established in order to be able to create a classification. Any deviation from the target value must be able to be identified. In the case of open standards, target values have not been established. The limit values and classification must therefore still be determined manually.

11 Rules (GDPR) on privacy for slaughterhouse staff

The cameras and microphones installed at the slaughterhouse will also record images and audio of the slaughterhouse employees and this is subject to certain rules, such as the The General Data Protection Regulation (GDPR).

Appendix 1 Literature review search strategy

1 A search was conducted on Google Scholar and Pubmed for the terms 'animal based measures' combined with 'slaughterhouse' and then combined with 'pig' and 'cattle', as well as for 'computer vision abattoir' and 'measuring fever infrared animal'.
2 Knowledge and awareness of BuRO coworkers regarding (recently) published articles on sensor technology in livestock farming.
3 Existing publications and books on animal welfare in the possession of BuRO relating to sensor technology in livestock farming.
4 'Snowballing' (using reference lists of literature retrieved).
5 Advisory reports previously published by BuRO: (BuRO, 2015;2017;2018b;2018a;2020b;2020a;2021).
6 NVWA publications: (NVWA, 2020b;2020a;2021e;2021d;2021c;2021a)

Appendix 2 NVWA supervision at slaughterhouses

Slaughterhouses can be classified into three categories (NVWA, 2020b):

1. Slaughterhouses under permanent supervision
2. Slaughterhouses that slaughter more than 1000 LU[25] of red meat and/or 150,000 head of poultry, lagomorphs, small wild game per year
3. Slaughterhouses that slaughter less than 1000 LU of red meat and/or 150,000 head of poultry, lagomorphs, small wild game per year

The slaughter rates and/or numbers of animals slaughtered per week are determining factors for permanent supervision. For cattle, for example, this is more than 250 head of cattle per week and/or 25 per hour; for calves this is more than 500 per week and/or 50 per hour; for finishing pigs this is more than 2000 per week and/or 200 per hour and for poultry this is more than 15,000 per week and/or 1500 per hour. For group 2, the NVWA determines whether permanent supervision is required or not by means of a risk assessment. The NVWA has classified the slaughtered animals into groups with an increased risk in terms of animal health, public health and animal welfare. In order to reduce the foregoing risks, it has been determined that specific high-risk groups of animals may only be slaughtered and undergo PM inspections under permanent supervision. Other groups of animals can be slaughtered and undergo PM inspection without permanent supervision if the quality supplied is high (>95% AM category 1, healthy animals with no abnormalities). Veal calves and finishing pigs, for example, fall into the low risk group of animals. Culled cows from dairy farms and sows and boars from breeding farms, for example, fall into the animal group at an elevated risk and may only be slaughtered at category 2 slaughterhouses under permanent supervision. For category 3 slaughterhouses, it is similarly determined whether or not the slaughterhouse is subject to permanent supervision based on the slaughter rate, the number of slaughtered animals per week and animal group slaughtered. In the absence of permanent supervision, then supervision will take place by the NVWA on a weekly or monthly basis, depending on the slaughter rates and/or numbers of animals slaughtered per week.

[25] LU = Livestock unit, an agricultural conversion factor. An adult cow is equal to 1 LU and a finishing pig is equal to 0.2 LU.

Appendix 3 Details of NVWA supervision and inspection remit at poultry slaughterhouses

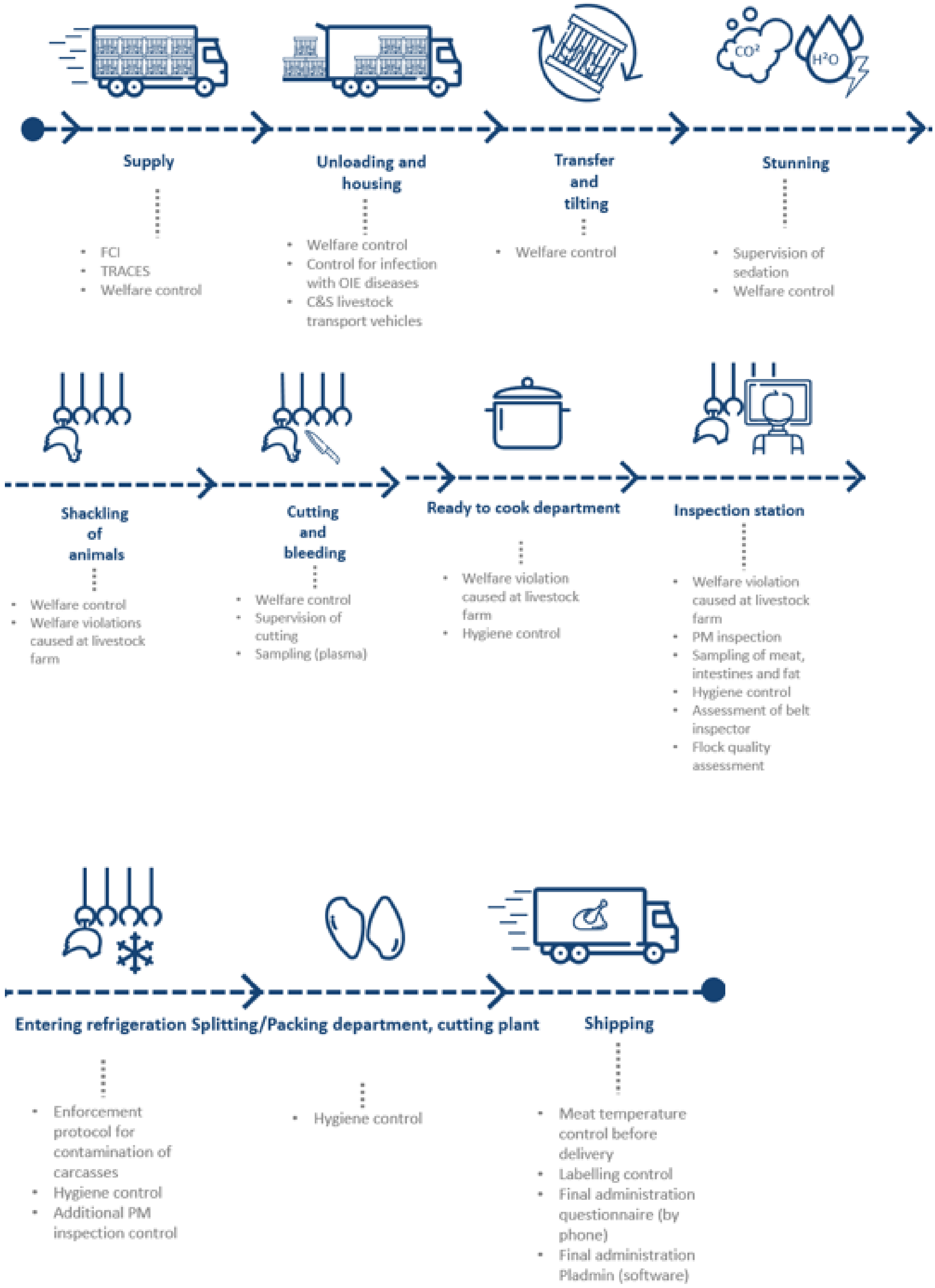

Figure 24 NVWA supervision and inspection remit at poultry slaughterhouses Source: NVWA (2021b).

Appendix 4 Tables outlining animal-based measures for poultry, pigs and cattle measurable at the slaughterhouse

Based on recent EFSA reports on the welfare of poultry, cattle and pigs at the slaughterhouse (EFSA, 2019;2020a;2020b) and Welfare Quality protocols (Welfare Quality®, 2009b;2009c;2009a), an assessment was drawn up of animal-based measures and the associated welfare consequences that can be measured at the slaughterhouse. The principles and criteria of Welfare Quality are used to structure the welfare consequences and animal-based measures.

Table 3. Welfare Quality principles and criteria (Jones & Manteca, 2009).

Principles	Criteria
Good feeding	1. Absence of prolonged hunger 2. Absence of prolonged thirst
Good housing	3. Comfort around resting 4. Thermal comfort 5. Ease of movement
Good health	6. Absence of injuries 7. Absence of disease 8. Absence of pain induced by management procedures
Appropriate behaviour	9. Expression of social behaviours 10. Expression of other welfare related behaviours 11. Good human-animal relationships 12. Positive emotional state

Table 4 Animal-based measures assessed at the slaughterhouse and welfare consequences in poultry applicable to the welfare at the farm, during transport or at the slaughterhouse based on Welfare Quality® (2009c) and EFSA (2019).

Welfare consequence	Animal-based measure	Farm	Transport[26]	Slaughterhouse
Good feeding				
Prolonged hunger	Presence of bile and/or presence of urates or orange discharge at the bottom of the containers		x	x
Prolonged hunger farm	Emaciated animals	x		
Dehydration	Dehydrated animals	x	x	
Good housing				
Heat stress	Panting		x	x
Cold stress	Huddling		x	x
	Piloerection		x	x

[26] There is no separate Welfare Quality protocol to assess welfare with regard to transport, however, the assessment relating to welfare at the slaughterhouse also includes and outlines phases that fall under transport. BuRO has also classified these indicators as falling under the transport phase based on its own insight and knowledge.

	Shivering		x	x
Limited movement	Pilling up (overcrowding in container)		x	x
Good health				
Injuries (pain)	Breast blisters	x		
	Hock burn	x		
	Footpad lesions	x		
	Wing injuries (bone fractures)		x	x
	Bruising		x	x
Disease	Ascites	x		
	Septicaemia	x		
	Hepatitis (liver inflammation)	x		
	Pericarditis (inflammation of the pericardium)	x		
	Abscesses	x		
Death	Dead on arrival (DOA)		x	x
Respiratory stress during stunning	Deep breathing			x
	Hyperventilation			x
Pain during stunning/ killing	Muscle spasms			x
	Withdrawal reflex			x
Consciousness during killing process	Attempt to regain posture			x
	Maintenance of posture			x
Appropriate behaviour				
Fear	Bunching			x
	Wing flapping			x
Fear and pain	Escape attempts			x
	Shaking head			x
	Vocalisations			x

For animal-based measures in cattle, Losada-Espinosa et al. (2018) also assessed the degree of validity and applicability to the slaughterhouse. High validity exists if the indicators have been validated in a large number of scientific articles. Indicators with a high degree of applicability to the slaughterhouse are indicators that can be measured independently of the number of animals, the speed or the space at the slaughterhouse.

Table 5 Animal-based measures assessed at the slaughterhouse and welfare consequences in cattle applicable to welfare at the farm, during transport or at the slaughterhouse based on Welfare Quality® (2009b) and EFSA (2020b). Indicators with a high validity and degree of applicability to the slaughterhouse according to Losada-Espinosa et al. (2018) are underlined.

Welfare consequence	Animal-based measure	Farm	Transport[27]	Slaughterhouse
Good feeding				
Prolonged thirst	Increased aggression at drinking trough		x	x
Good housing				
Heat stress	Panting			x
Cold stress	Shivering			x
Restricted movement	<u>Slipping</u>			x
	<u>Falling</u>			x
Good health				
Injuries (pain)	<u>Bruising</u>		x	x
Lameness (pain)	Lameness		x	x
Fatigue	Exhaustion		x	x
	Rapid breathing (tachypnoea)			x
Consciousness during stunning and killing process	<u>Posture</u>			x
	<u>Body movement</u>			x
	<u>Breathing</u>			x
	Tonic seizure			x
	<u>Cornea and/or palpebral reflex</u>			x
	Spontaneous blinking			x
	<u>Eye movements</u>			x
	<u>Muscle tone</u>			x
Appropriate behaviour				
Social stress	<u>Aggressive behaviour</u>			x
	Mounting			x
Fear	Escape attempts			x
	<u>Turning around or moving backwards</u>			x
	<u>Struggling in the stunning box</u>			x
	<u>Jumping in the stunning box</u>			x

[27] There is no separate Welfare Quality protocol to assess welfare with regard to transport, however, the assessment relating to welfare at the slaughterhouse also includes and outlines phases that fall under transport. BuRO has also classified these indicators as falling under the transport phase based on its own insight and knowledge.

Fear and pain	Reluctance to move, freezing			x
	Vocalisations			x

Table 6 Animal-based measures assessed at the slaughterhouse and welfare consequences in pigs applicable to welfare at the farm, during transport or at the slaughterhouse based on Welfare Quality® (2009a) and EFSA (2020a).

Welfare consequence	Animal-based measure	Farm	Transport[28]	Slaughter-house
Good feeding				
Prolonged thirst	Increased aggression at drinking trough		x	x
Good housing				
Heat stress	Panting		x	x
	Discolouration of the skin		x	x
Cold stress	Shivering		x	x
	Huddling		x	x
Restricted movement	Slipping			x
	Falling			x
Good health				
Injuries (pain)	Bruising, scratches, broken bones, etc.		x	x
Lameness (pain)	Lameness		x	x
Fatigue	Exhaustion		x	x
	Shortness of breath and open mouth breathing (dyspnoea)		x	x
	Muscle tremors		x	x
Disease	Pneumonia	x		
	Pleurisy	x		
	Pericarditis (inflammation of the pericardium)	x		
	White spots on the liver	x		
	Sick animals		x	x
Respiratory stress during CO2 stunning	Gasping for air			x
	Hyperventilation			x
	Shaking head			x

[28] There is no separate Welfare Quality protocol to assess welfare with regard to transport, however, the assessment relating to welfare at the slaughterhouse also includes and outlines phases that fall under transport. BuRO has also classified these indicators as falling under the transport phase based on its own insight and knowledge.

Consciousness during stunning and killing process	Posture			x
	Body movement			x
	Breathing			x
	Tonic and clonic seizures			x
	Cornea and/or palpebral reflex			x
	Spontaneous blinking			x
	Eye movements			x
	Muscle tone			x
Appropriate behaviour				
Social stress	Aggressive behaviour			x
	Mounting			x
Fear	Reluctance to move, freezing			x
	Turning or walking backwards			x
Fear and pain	High-pitched vocalisations			x
	Escape attempts			x

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