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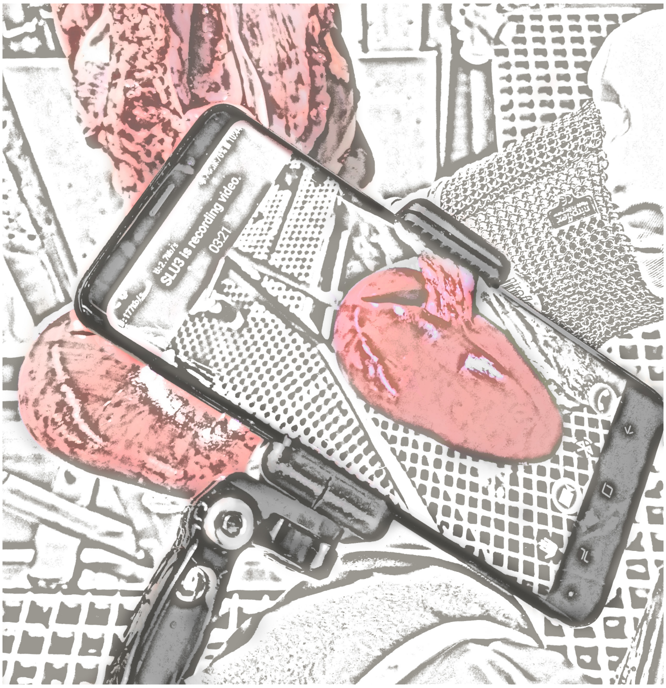
# Who you gonna call?

## Examining the possibilities of remote veterinary meat inspection

Viktor Almqvist



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# Who you gonna call? Examining the possibilities of remote veterinary meat inspection

## Abstract

Demand for locally produced meat from small-scale slaughterhouses and game-handling facilities brings severe logistical challenges in meat inspection, since such facilities are often situated in rural areas and the costs and time associated with inspection visits to remote establishments are significant. With advances in technology, it might be possible to conduct meat inspections remotely via video link.

This thesis aims to determine the performance of remote inspections, both *ante mortem* and *post mortem*, where a guided, untrained assistant present at the slaughterhouse relays video and sensory impressions to a veterinarian off-site. Performance was evaluated based on agreement between remote and on-site inspections. As part of this, a practical technological solution, with emphasis on a less-is-more approach, was conceived, assembled and tested in practical use.

Comparisons between methods were conducted using Cohen's kappa-based statistics. On directly comparing findings under 26 different inspection codes or classifications recorded by two veterinarians conducting inspections on 400 carcasses and organs of pigs at a Swedish large-scale slaughterhouse, it was found that the level of agreement between the two methods was generally high, with most findings scoring 'almost perfect agreement'. When *ante mortem* inspections were evaluated in a similar way, it was concluded that, due to extremely low prevalence of findings, *ante mortem* inspections are difficult to perform remotely under current conditions.

In conclusion, remote *post mortem* veterinary inspections appear very promising, but the method needs to be evaluated further.

*Keywords:* digital, *post mortem*, livestock, slaughter, official veterinarian, video, augmented reality, inspection, remote

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# Who you gonna call? En undersökning av möjligheterna kring distansbaserad köttbesiktning

## Sammanfattning

Med ökad efterfrågan på närproducerat kött från småskaliga slakterier och vilthanteringsanläggningar följer stora logistiska utmaningar. Eftersom dessa anläggningar ofta är belägna på landsbygden är kostnaderna och tidsåtgången för resor till och från anläggningarna avsevärda. Modern teknik kan göra det möjligt att genomföra köttbesiktning på distans, via videolänk.

Den här avhandlingen söker fastställa hur fjärrbesiktning vid slakt fungerar, både *ante mortem* och *port mortem*, genom att låta en instruerad, oerfaren assistent på plats på slakteriet förmedla både video och sinnesintryck till en veterinär på annan plats. Utvärderingen baserade sig på samstämmighet mellan fjärrbesiktning och besiktning på plats. Som en del i detta togs en teknisk lösning fram, med tonvikt på ”less-is-more”, som sedan testades genom praktiskt användande.

Jämförelserna mellan metoderna gjordes med hjälp av Cohen’s kappa-baserad statistik. Genom att direkt jämföra förekomsten av fynd för 26 olika inspektionskoder eller klassificeringar mellan två veterinärer som genomförde besiktningar av 400 slaktkroppar och organ från grisar på ett svenskt storskaligt slakteri, befanns att samstämmigheten mellan metoderna generellt var hög: Merparten av fynden uppvisade ”nästan perfekt överenstämmelse”. När besiktning *ante mortem* bedömdes på ett liknande sätt drogs slutsatsen att metoden inte kunde utvärderas för den besiktningen under dessa former på grund av extremt låg prevalens av fynd.

Sammanfattningsvis verkar fjärrbaserad veterinär slaktbesiktning vara mycket lovande, men metoden behöver utvärderas ytterligare.

*Nyckelord:* digital, *post mortem*, slakt, augmented reality, video, produktionsdjur, officiell veterinär, inspektion, distans

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# Dedication

To my son Ture; in hopes of a better tomorrow.

# Contents

# List of publications

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

I. Almqvist, V., Berg, C. & Hultgren, J. Creating a technical solution for veterinary meat inspection through augmented-reality remote guidance using commercially available products. *(manuscript)*

II. Almqvist, V., Berg, C. & Hultgren, J. (2021). Reliability of remote post-mortem veterinary meat inspections in pigs using augmented-reality live-stream video software. *Food Control 125*, 107940*.*

III. Almqvist, V., Berg, C. & Hultgren, J. Inter-rater agreement in a group of official veterinarians evaluating pre-recorded remote meat inspections at pig slaughter. *(manuscript)*

IV. Almqvist, V., Berg, C. & Hultgren, J. Evaluating the inter-method, intra-rater reliability of remote post-mortem veterinary meat inspections in pigs using pre-recorded video material. *(manuscript)*

The contribution of Viktor Almqvist to the papers included in this thesis was as follows:

I. Conceptualisation, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – reviewing & editing, visualisation.

II. Conceptualisation, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – reviewing & editing, visualisation.

III. Conceptualisation, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – reviewing & editing, visualisation.

IV. Conceptualisation, methodology, software, validation, formal analysis, investigation, resources, data curation, writing – original draft, writing – reviewing & editing, visualisation.

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# Abbreviations

| | |
|---|---|
| 3G, 4G, 5G | 3rd,4th,5th, generation cellular networks |
| AM | *Ante mortem* |
| FA | Falsely arrested |
| LAN | Local area network |
| LC | Local condemnation |
| OA | Official auxiliary |
| OV | Official veterinarian |
| PABAK | Prevalence- and bias-adjusted kappa |
| PM | *Post mortem* |
| TC | Total condemnation |
| WLAN | Wireless local area network |

# 1. Background

In recent decades, the meat production industry in Sweden has undergone a significant shift towards small-scale operations. Between 2006 and 2010, 28 new small-scale slaughter facilities were approved by the authorities, and in 2020 there were 86 such facilities. The number of game-handling facilities has also increased, with a total of 149 in operation across Sweden in 2020. Hultgren *et al.,* (2016) performed a risk assessment of animal welfare at small- and large-scale slaughter of sheep in Iceland, Norway, Sweden and Finland, and found most animal welfare risks to be lower at small-scale slaughter.

Rearing of animals in Sweden, and in several other countries, is also undergoing changes. Average herd size is increasing, leading to reduced human contact for the individual animal, which could make them less accustomed and tolerant to human handling at slaughter (Bunzel-Drüke *et al*., 2009). Small-scale slaughter, especially in close proximity to the farm of origin, could increase animal welfare and improve conditions for the animals, for instance by shorter transport of livestock to the slaughter plant, thereby reducing animal stress (Hultgren, 2018).

The European Union (EU) is prioritising continued digitalisation, and the Swedish Government places much emphasis on sustainability and development of small-scale production in its food strategy (Swedish Government, 2017a). In order to maintain a living countryside, small-scale animal producers are essential. The Swedish government considers it of great importance to increase Sweden’s degree of self-sufficiency with regard to foodstuffs, in order to decrease reliance on imports (SOU 2015:15). The government has tasked the Swedish Food Agency with optimising and streamlining official control in Sweden (Government Offices of Sweden, 2017a, 2017b). This PhD project was carried out at the request of the Swedish Food Agency, as part of a larger mission to increase efficiency and reduce costs of official control in Sweden.

# 2. Introduction

## 2.1 Slaughter and inspections

### 2.1.1 Slaughter

The process of transforming animals into food for humans is a long one. The animals are bred on a farm and, when a certain live weight is reached, they are rounded up and transported to their final destination. When they arrive at the slaughter facility they are unloaded and put into lairage pens, where they will wait until slaughter. The animals are then taken for stunning, which can be performed using a number of different methods. The aim of stunning is to ensure that the animals are unconscious before the next step, exsanguination. This is what effectively kills the animal and removal of the blood helps keep the quality of the meat intact.

After the animal has been stunned and bled, the rest of the slaughter process commences. It varies between species, but basically the carcass is either skinned or, in the case of swine, scalded and torched. The carcass is then further processed by the removal of the distal extremities and external genitalia, and eviscerated. The next step is usually to split the carcass into two halves, which are trimmed to remove any visual contaminants, and weighed and classified according to muscle and fat content before being put into cold storage. Game animals that have been killed by hunters are processed at special game-handling facilities and obviously arrive at the facility already dead. Apart from this, the procedures are very similar.

### 2.1.2 Official inspections

A well-functioning official control system at slaughter and game handling is a prerequisite for safe meat products and for good animal welfare and detection of infectious diseases in livestock. Official control at slaughter and game-handling facilities is regulated by the EU (EU, 2017, 2019a, 2019b), and to a lesser extent by national guidelines (Swedish Food Agency, 2005). All animals destined for slaughter must be inspected *ante mortem* (AM) by an official veterinarian (OV) employed by the Swedish Food Agency. The inspection is performed with regard to food safety and detection of any infectious disease and animal welfare aspects. All animals are presented to the OV before slaughter, either in pens or during unloading. The OV checks for any signs of illness or injury, and approves the animals for slaughter if no major problems are found. *Post mortem* (PM) all carcasses and organs are inspected, by either an OV or, perhaps more commonly, a delegated official auxiliary (OA). The inspections are rather quick to perform, often taking less than a minute per animal. This inspection focuses primarily on food safety by determining any presence of pathological or qualitative lesions making the meat unfit for consumption, but certain animal welfare-related issues and infectious diseases can also be detected. These PM inspections are referred to hereafter in this thesis as OA inspections. They are carried out after the animal has been split and degutted, but before any trimming is performed. How the inspections are conducted varies between species of animals, but generally both the carcass and all internal organs are inspected visually. In pigs reared under controlled conditions, this is sufficient. In sheep, horses and cattle, the organs are additionally palpated and various incisions are made in order to evaluate their interior.

As mentioned, PM inspections are commonly carried out by OAs, but at small-scale slaughter facilities it is common for both AM and PM inspections to be carried out by an OV. Any lesions of a pathological or qualitative nature are recorded and trimmed off, so called local condemnation (LC). If during PM inspection there are signs that the carcass poses a potential hazard to consumers if consumed or if for any other reason it requires more in-depth inspection, the carcass and organs can be arrested for further inspection. An OV will then perform a thorough inspection, and based on the findings and their severity will either clear the material for consumption after all offending findings have been removed, or declare the carcass unfit for consumption (total condemnation, TC), after which it and all accompanying organs and by-products are destroyed.

### 2.1.3 Legislation and costs of small-scale slaughter

Both AM and PM inspections must be performed on-site (EU, 2017), and thus require personnel from the competent authority (in Sweden; the Swedish Food Agency) to be present at each slaughter plant or game-handling facility. For large-scale facilities, usually situated in urban areas, inspection personnel are present during all working hours. However at smaller plants (often in a more rural setting), they usually visit once or twice per day, travelling from a more central location, to perform inspections. This entails substantial costs for the Swedish Food Agency, both in terms of fuel and vehicles, but also man-hours spent travelling. In northern Sweden in particular, distances to smaller, more remote plants can be substantial. It is estimated that in 2020, small-scale slaughter and game-handling facilities contributed only 3.5% of total Swedish red meat production but accounted for around 26% of the total time spent on AM and PM inspections (Arja Helena Kautto, Swedish Food Agency, personal communication, October 22, 2020).

The costs of official control within meat production are borne mostly by the slaughter companies themselves (Stärk *et al.*, 2014; EU, 2017), and elevated costs for the Swedish Food Agency are thus transferred to the companies. These costs have been described by the industry as “excessive” (Arzoomand *et al.*, 2019), and since small-scale facilities process fewer animals in any given time-frame, the cost per animal for official control would be higher for smaller companies, chipping away at their profit margins. With fuel costs expected to rise in the future, these costs are bound to increase over time. In addition, there are environmental issues connected to travelling, as well as personnel safety concerns with spending hours on the road in sometimes harsh conditions or remote, sparsely populated areas.

### 2.1.4 Improving efficiency by technological means

The Swedish Food Agency has identified digitalisation as a means to further develop the official inspection system and optimise operations (Swedish Food Agency 2017, 2018). The Swedish Government has given the Swedish Food Agency the task of streamlining official control at slaughter plants and game-handling facilities, in order to keep costs down (Government offices of Sweden, 2017b). The slaughter industry itself is quick to adopt technology to improve the quality of its products or to reduce labour costs. Technological developments range from automating the slaughter process itself (Nielsen *et al.*, 2014) to computer-vision-based systems for qualitative assessments of carcasses or meat details (Pabiou, 2012; Taheri-Garavand *et al.*, 2019).

One way to reduce costs and streamline official control would be to decrease the physical presence of inspection personnel at slaughter plants. This could be achieved through the use of digital communication and technological solutions. If inspections were carried out remotely, the inspector (OV or OA) could be stationed at a central office and the time previously spent travelling could instead be used for other assignments. This would allow for handling of more than one slaughter facility at a time and for rotating personnel between slaughter plants without geographical constraints. It might even simplify recruitment of new personnel since geographical location would no longer be important, which would broaden the pool of potential candidates, especially in remote regions of Sweden.

Since meat inspection is a fairly complex task, requiring at the very least viewing the material from multiple angles and for some species both routine palpation and incisions, it still involves handling of the material. If the OA or OV is not present at the slaughter site, someone else (an assistant) will have to perform these tasks in their place. The obvious candidate is someone who is already present at the facility, *i.e.* someone employed by the company in question. This assistant would then work in tandem with the remote inspector to relay the necessary video footage and perform any tasks and examinations required for the inspection.

Being what it is, digital communication forces remote veterinary inspections at slaughter, both AM and PM, to be limited to visual and auditory inputs. Although touch can in theory be relayed through haptic feedback, it is unreasonable to use in this context, while smell (and taste) so far cannot be transferred digitally. Thus, the veterinarian is reliant on the person assisting with inspections to relay these sensory impressions. Since meat inspection requires training and certification, which this assistant most likely lacks, the OV or OA would need to be in constant communication with them in order to give directions on how to complete the task at hand. This verbal relaying of information and instructions of course carries a risk of miscommunication, intentional or otherwise, and requires the OV to be very clear and concise in their instructions.

In 2014, a change was made in the EU legislation to allow for purely visual PM inspection of carcasses of pigs reared under so-called ‘controlled conditions’, instead of the previous palpation- and incision-based inspection (Hill *et al.*, 2013; EC, 2014). This change was motivated by a gradual shift in the spectrum of hazards over the years, from gross pathological lesions to microbial contaminants. By reducing manual handling of the carcasses and organs, the risk of microbial contamination is decreased (Pointon *et al.*, 2000; Nesbakken *et al.*, 2003). Furthermore, visual inspection improves cost-effectiveness because more carcasses can be inspected within a set time frame (Calvo-Artavia *et al.*, 2013). Studies conducted in advance showed no marked increase in risk for consumers as a result of this legislative change (Mousing *et al.*, 1997; Calvo-Artavia *et al.*, 2013; Hill *et al.*, 2013; Stärk *et al.*, 2014). Purely visual inspections were shown to be equally good at determining disease, but it was also concluded that a majority of the gross findings recorded during PM inspections do not pose a risk to the human population (Mousing *et al.*, 1997; EFSA, 2011; Hill *et al.*, 2013). A recent survey in Finland showed that meat inspectors regard limited visibility due to non-tactile interaction as an obstacle to visual meat inspection (Laukkanen-Ninios *et al.*, 2020).

As the inspector is currently required to be physically present at the slaughter facility, the legislation would have to be changed to allow remote inspections to take place. If remote veterinary inspections can be shown to be equally reliable to established on-site inspections, combined with prospective financial and ecological savings, another change in the EU legislation may be motivated.

## 2.2 Internet connectivity and video transmission

### 2.2.1 Telemedicine

In a 1962 episode of the cartoon The Jetsons (Hanna-Barbera Productions, Inc., Los Angeles, USA), the family’s son Elroy claims to have contracted a virus and wants to stay home from school. Suspecting malingering, his mother decides to call the doctor. Instead of going to the doctor’s office or receiving an ordinary house call, the doctor instead appears on a large screen in the house. He asks the boy to open his mouth, looks into it and concludes that the boy is simply faking. The Jetson family is supposed to live in the year 2030 and, while we are a long way from their futuristic flying cars or cities in the sky, the scene with the doctor is in fact reality today.

Telemedicine is defined by the Cambridge dictionary as “medical treatment that involves sending information from one place to another using computers, video, *etc*.” (Cambridge University Press, 2021). While the idea of visiting the doctor without leaving home might sound appealing, the technology has arguably more important benefits in rural areas (Jin & Chen, 2015) or less developed countries (Abate *et al.*, 2017). Even the clinical veterinary sector has seen services emerge based on these ideas (Oxley & Saunders, 2015), with Sweden having several commercial actors on the emerging market.

Computers have been used for automation purposes in veterinary hospitals since the 1960s (Rogers, 1996). Today, they assist in laboratory testing (Dórea *et al.*, 2013) and diagnosis using image analysis (Inácio *et al.*, 2020), along with several other clinical tasks. Bertram & Klopfleisch (2017) argue that continuing digitalisation of veterinary pathology in general, and microscopy in particular, is unavoidable.

### 2.2.2 Video calls and augmented reality

In order to perform veterinary inspections from a remote location, the inspector must be able to see what is inspected. One way of relaying that information over a distance is through streamed video using the internet. Due to the complexity of veterinary meat inspection, two-way communication between inspector and assistant is paramount.

Skype (Microsoft, Inc., Redmond, CA, USA) could be argued to be one of the forefathers of internet-based video calls. At the very least, it was the software which made video calling available to the broader masses. Today there is a slew of different software, both commercial and free, that enables calls using video. A niche market of video calling software now incorporates augmented reality as a tool for providing on-site technical support.

Augmented reality, defined as “technology that combines computer-generated images on a screen with the real object or scene that you are looking at” (Oxford University Press, 2021), has recently emerged in arenas from entertainment to teaching. Envisioned as early as 1901, in the novel “*The Master Key*” by L. Frank Baum, the technology has been also suggested for use in *e.g.* medical and military applications (Azuma, 1997).

In contrast to virtual reality, in which the user is immersed in a computer-generated world, augmented reality instead seeks to enhance reality by providing new information without compromising what the user already sees (Billinghurst, 2002). In recent years, one of the most well-known uses of augmented reality is perhaps the mobile game Pokémon GO (Niantic, Inc., San Francisco, California, USA/The Pokémon Company, Tokyo, Japan), with over 1 billion cumulative downloads by 2020 (Business of Apps, 2021), where the technology is used to allow capture of fictional monsters (Pokémon) in the real world.

Since augmented reality strives to complement reality with additional information, it could be a valuable tool for teaching and transfer of complex instructions that are more suited to visual than verbal explanations. (Billinghurst, 2002; Yip *et al.*, 2019). In medicine, the technology has been used *e.g.* in on-the-fly training of technicians to perform ultra-sonic evaluations (Wang *et al.*, 2017), in teaching untrained users to place electrocardiogram electrodes (Bifulco *et al.*, 2014) or as a visual aid during surgeries (Haavik, 2016; Orring, 2017).

This simplicity in transfer of complex instructions could be of great importance by allowing an untrained assistant to perform the manual tasks associated with veterinary inspections at slaughter. As the concept of performing veterinary inspections at slaughter is new, no software specially tailored for this usage exists, at least not on the open market.

### 2.2.3 Transmission over the internet

There are currently three main alternatives for connecting to the internet: terrestrial-based, such as fibre-optic or digital subscriber line connections; cellular connections (3/4/5G); and satellite-based connections. All three have their strengths and weaknesses.

Data are sent over the internet as packets, small enough that a single frame of video is made up of many of them. These packets are sent from one user to the address of another (Caffery & Smith, 2015). Because the internet is interconnected like a web, they may take different routes to the end, and thus arrive at different times and sometimes in different order (Gemill, 2005). The packets are then assembled into whatever data they are supposed to be and displayed to the receiver.

There are three main factors of importance for communication over the internet: bandwidth, latency and jitter.

Bandwidth is how much data can be transferred in a given time frame. This is also sometimes referred to as the "speed" of the connection, and is measured in bits per second (bit/s) combined with a suitable prefix. A suitable analogy would be a river with boats travelling down it, with the boats being data packets. Electrical signals (the boats) travel at a fixed speed (the speed of light), and cannot travel faster. A wider river allows more boats to travel simultaneously, however, which means more data throughput in the same time frame. Bandwidth naturally has an effect on the quality of the received video; if more bandwidth is available, a higher-quality image can be sent. The available bandwidth needs to be at least equal to the bit rate of the video file, but a degree of overhead is of course recommended.

Latency is the time between initiation of information transfer and receipt of the information, *i.e.* how long it takes for the information to arrive, while jitter is random fluctuations in this latency, *i.e.* high jitter means that some data packets arrive faster than others. Both are measured in milliseconds (ms). In our river analogy, this is the time it takes for the boats to arrive at their destination, since their speed is finite. Some boats may take a longer route and arrive later than others, even if starting at the same time.

The latency in a video call also has a direct effect on the perceived quality of the call (Mody *et al.*, 2014). It has been suggested that delays below 150 ms are acceptable to users (Challacombe *et al.*, 2003; De Cristofaro *et al.*, 2009; Seuren *et al.*, 2021), but delays as low as 10-20 ms are required for extremely time-sensitive work such as tactile feedback in remote surgery (Anderson & Spong, 1989a, b) or orchestral performances (Ubik *et al.*, 2020).

### *Types of connections*

Terrestrial-based connections are generally very stable, but can be difficult and costly to install in remote areas if they require new cabling to be put in the ground over long distances.

Cellular connections are very mobile, but rely on coverage by the telecom operator and are sensitive to congestion in the net (*i.e.* the more users, the slower the connection). In addition, cellular reception favours line of sight, but the signal can still travel through materials other than air. The signal weakens with the more material it has to pass through, such as the walls of a building or other shadowing objects outside (Qazi *et al.*, 2015; Soliman *et al.*, 2020). Building materials also have an effect on signal attenuation, with thicker materials such as reinforced concrete being more difficult to travel through than glass, wood or drywall (Stone, 1997). The least permeable material is likely corrugated iron plating, which would act as a Faraday shield, blocking almost all electromagnetic signals (Martin, 2014; Chapman *et al.*, 2015). This type of material is commonly used as roofing or wall covering in small sheds or barns in Sweden.

Where 3G made video calls and mobile internet possible, 4G technology allows for video conferences and on-line games on-the-go (Haile *et al.*, 2021). At present, most mobile phone operators in Sweden boast of providing 4G coverage to over 99% of the population (Tele2, 2021; Telia, 2021), with some also claiming to cover over 90% of the country's surface area (Telia, 2021), and 5G nets are currently being deployed. This bodes well for allowing high-speed internet access even at remote slaughter plants in rural areas.

Satellite connections are also mobile solutions which rely on satellites in geostationary orbit to receive and relay the signal. This allows the technology to be used in areas where there is no other coverage and means of communication. The downside is that the signal requires line of sight and, due to the distance it needs to travel, there is high latency involved.

Terrestrial connections generally perform in the 15-25 ms range, with 3/4G cellular having slightly longer delays of around 40-60 ms (Hanson, 2016; Lema *et al.*, 2017). 5G introduces the ultra-reliable and low-latency communications standard, which is designed to facilitate *e.g.* tactility in remote medical procedures and the use of self-driving vehicles, and pushes the latency down to 1 ms (Li *et al.*, 2017). It is unclear what kind of bandwidth can be expected using this protocol. Satellite communication requires a minimum delay in the range of 250 ms, purely due to the distance the signal needs to travel up into geostationary orbit and back again, and often the delay is around 600 ms or more, 10-20 times higher than for terrestrial connections (Hanson, 2016).

As mentioned previously, most modern video-conferencing software relies on the h.264 or h.265 codec. This codec in and of itself adds a delay in the range of several tens of milliseconds to the call, due to the compression and decompression of the video (Ubik *et al.*, 2020). This delay is added on top of any delay caused by the connection itself.

Due to the branching structure of the internet, data packets can take multiple routes to their destination. Because of this, these packages sometimes get lost or take too much time to arrive due to latency or jitter.

This is handled by the receiver either ignoring the packet and hoping the data are not important enough for the user to notice, or asking the sender to send it again. Different data are preferably sent using different methods, and streaming video primarily uses the former, since there might not be enough time to wait for the re-sent packets (Gemill, 2005). A small amount of packet loss can be handled, but if too many go missing it will cause a lowering of the video quality (Caffery & Smith, 2015). Since live video is exactly that, it cannot be buffered to any large extent and thus network instabilities can quickly cause quality degradation or dropped calls.

### 2.2.4 Video files and compression

*Video files*

Video, from the Latin *vidae* (to see), is a moving series of still images, often together with an audio track. A video file's quality is determined by its resolution (how many points, or pixels, make up the image) bit-depth (how many bits of information are used to represent the colour of each pixel) and frame rate (how many still images are displayed per second).

Today a common resolution is 1920x1080 pixels, or 1080p, at 24-bit colour depth. This gives about two million pixels per still image. Each pixel is assigned an 8-bit value (0-255) for each of the three primary colours (red, green and blue) and the combination of values gives the pixel its colour. This is referred to as 24-bit colour depth, and translates to about 16.7 million ($2^{24}$) different colours being represented. Humans can discern about 10 million different colours (Judd & Wyszecki, 1975), and the 24-bit colour depth is deemed sufficient to represent all these colours in a video.

Frame rates over 16 frames/second appear fluent to humans (Read & Meyer, 2000). In order to store a single image, it is thus necessary to store 2 million entries of 3 x 8 bit values. This amounts to 1920 x 1080 x 3 x 8 = 48 Mbit, or 6 Mbyte. At 30 frames per second, a video would require around 1.5 Gbit/s of bandwidth to transmit, excluding any audio component. These bandwidths are rarely available even in local area networks (LANs), and much less so over the internet. The video size can be lowered either by lowering the absolute quality (*e.g.* using lower resolution or colour depth) or by compression.

*Compression*

Compression uses patterns in the data in order to decrease the size required to store information. For a single frame of 1080p video which is entirely the same colour, instead of listing two million entries of “this pixel is red”, there can be a single entry of “all two million pixels are red”, which of course requires much less space to store. When viewing the image, this information is read and an image is calculated and drawn based on the instructions. The relationship in size between the original image and the compressed image is called the compression ratio, or simply compression.

If the image is more complex, say a horizontal gradient from red to white, the compression instead works by storing certain areas of the image (in this case 256 vertical bands) as being the same colour. This requires more information than saying the entire image is one colour, but still substantially less than storing the value of each pixel individually.

If the information of interest is merely the fact that the image represents a gradient from red to white, and not exactly how detailed it is, choosing to say that colours close together in appearance are in fact the same can decrease the size further, since even less information about the gradient needs to be stored. Instead of 256 entries, each with its own colour, now only five need to be stored (Figure 1).

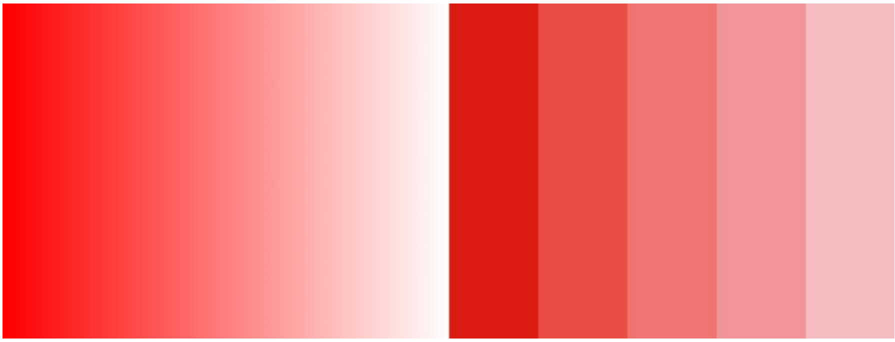


*Figure 1.* (Left) Detailed colour gradient and (right) gradient with lower detail.

As displayed in Figure 1, both images represent a gradient from red to white (or at least pink), but much less information needs to be stored in the right-hand example. Note that there are images which cannot be compressed at all. An image where each pixel is a unique random colour is one such example, as there are no patterns for the compression algorithm to work off.

When storing a series of images (as a video file), compression can be taken one step further. For a video consisting of five frames of the same compressed 5-band gradient as before, instead of storing the same image five times, it can be stored once, followed by “the next four frames look the same”. Now five frames of, arguably very boring, video can be stored using almost no more storage space than would be required by a single frame.

If the image is not 100% static, but rather changes slightly from one frame to the next, things become a little more complicated. Assume that in frame 3 the second band of colour changes to be the same as the first. Instead of storing the entire “new” image, the relative change from one frame to the next can be stored, in this case that band 2 is now red instead of pink, and all the other parts are the same as in the previous frame.

This leads to the logical conclusion that videos consisting of very small changes over time, for instance static surveillance footage, are much easier to compress to small size than *e.g.* an action film filled with rapid movements.

Compression comes in two variants, lossless and lossy. Lossless compression, as the name implies, does not remove any part of the data present. The detailed gradient to the left in Figure 1 is one such example. The gradient is stored using compression (since not all 2 million pixels are stored), but all data are retained since the original image actually consisted of 256 bands of various shades of red.

In second gradient in Figure 1 is an example of lossy compression. Clumping the bands of colour together gives a smaller image size and a sufficient facsimile, but from the compressed image one cannot be certain how the original looked; it might have been like the left part of Figure 1, or perhaps exactly the same five bands to the right.

In fact, video compression is far more complex than the above example, often using advanced mathematical operations to determine how best to compress any given frame based on what the compression algorithm decides is information that can be thrown away or not. So-called video codecs handle this compression, which often targets a specific bit rate for the finished video. This bit rate can be either fixed, *i.e.* the same throughout the video, or an average number across the entire file, which allows for momentarily higher bit rates to be used in order to preserve details in certain frames, while other frames are compressed more heavily.

The most commonly used video codec in on-line video calls is the h.264, or advanced video codec, standard. This strikes a suitable balance between computational intensity and achieved compression. A more modern variant is h.265, or high-efficiency video codec, which, while being more demanding in terms of computational power, delivers the same image quality at about twice the compression (Pourazad *et al.*, 2012).

# 3. Aims

The overall aim of this thesis was to investigate the potential for veterinary inspections at slaughter to be carried out remotely and to devise and test a technological solution which facilitates this.

The specific objectives of the different studies in Papers I-IV were to:

- Study I: Describe the requirements of a technological solution for performing remote veterinary inspections at slaughter, and evaluate how such a solution would perform when conducting remote inspections (Paper I).

- Study II: Evaluate the performance of remote veterinary inspection, through comparison to veterinary inspections performed on-site (Paper II).

- Studies III and IV: Determine the cause of any low agreement between on-site and remote inspections in study II through mapping intra-group agreement within a group of official veterinarians performing inspections on pre-recorded video material (Paper III), and intra-rater, intra-method agreement when the same rater performs inspections using both methods on the same material (Paper IV).

In addition to the above objectives, an attempt was made to provide a mathematical indication of when it is economically viable to perform remote veterinary inspections.

# 4. Material and Methods

## 4.1 Study 1 (Paper I)

### 4.1.1 Requirements

In order to create a viable technological setup for remote animal and meat inspection, the entire slaughter process, with its unique challenges, had to be taken into consideration. A balance between ergonomics, safety and features had to be struck, while also keeping the overall complexity of the system to a minimum. The device had to, as a basis, convey enough information to the person conducting the remote inspection, which basically meant that the device had to be able to record video. In order to make the process of remote inspections as simple as possible, six additional requirements and preferences were also identified.

First, the device had to relay communication in real time to the inspector and to the assistant. The information consisted of the video stream for the inspector to inspect and, at a bare minimum, auditory instructions back to the assistant. This meant that the device either needed be equipped with speakers or connected to a pair of headphones. Further, it would be preferable if the assistant knew exactly what the inspector was seeing, meaning the device needed to have a display of some sort that showed what was currently being filmed and relayed. In particular, the use of augmented reality was considered in this thesis, meaning that the assistant needed to receive these visual aids.

Second, all the information and communication back and forth between inspector and assistant had to be transmitted. Since the receiving terminal could not be expected to be at the same facility, this transmission had to occur over the internet in some fashion. Based on the obvious requirement of portability, this meant the device had to be equipped with WiFi and/or a 3/4/5G modem, or some other solution for wireless communication.

Third, the device had to be mobile. Inspections of animals and carcasses are rarely performed in a fixed spot, meaning the device had to be freely movable around the facility. This limited its size and weight and introduced the requirement for a portable power source. In addition, the device could not occupy the assistant's hands, as both hands are required for performing meat inspections. Because of this, the device had to be somehow wearable and preferably not too heavy or bulky.

Fourth, the device had to be hygienic. Inspection of live animals is done in the slaughter facility's lairage areas which, although cleaned between groups of animals, are often soiled with faeces and dirt from the animals, some of which can be flung upwards by the animals' movements. Slaughter and meat inspection, in turn, involves varying degrees of blood or other tissue remnants. The hands of the meat inspector of course come into contact with this material through palpation and organic material can thus be transferred onto the device, *e.g.* through handling its controls. Thus it was imperative that the device could be easily cleaned and preferably disinfected, especially if the same device was used in both the lairage area and after slaughter. In this criterion, personal hygiene also had to be included, *e.g.* sharing a pair of headphones or other equipment worn close to the face or in direct contact with skin may not be acceptable to everyone.

Fifth, the entire solution had to be economically viable to purchase and maintain. If the ultimate goal of remote inspections is cost reduction, the technological solution cannot entail large investment costs, since that would defeat the purpose and the savings could be undone by investment costs and the need for complex setups in remote areas (Wang *et al.*, 2017). Every slaughter facility using remote inspections would need its own device, since it cannot be brought from place to place. The device also needed to be simple enough to put on and operate, so as not to introduce a cumbersome task for the person assisting in the remote inspections, and preferably the entire solution had to be easy to use, troubleshoot and service or replace.

Sixth, the device had to be safe to use. The environment of a slaughter plant is often loud, damp, moist and filled with unsafe elements. These range from people walking about with sharp objects to automated cutting or tearing machines and conveyors carrying carcasses and viscera around the facility. Any device relaying information to the user must be in a position where the user's eyes are not obscured and must allow the user's focus to be easily shifted away from the device to whatever danger might be present.

### 4.1.2 The hardware

Various hardware designs were conceived and rejected. Smart glasses in conjunction with a smartphone were rejected due to safety (Krupenia & Sanderson, 2006; Liu *et al.*, 2009), hygiene and economic reasons. A portable battery-powered x86-based micro-PC with a standalone arm-worn display and separate, USB-connected camera(s) was deemed overly complex and difficult to maintain, make waterproof and manage, especially when using off-the-shelf components.

It was concluded that a finished product which managed to fit every criterion already existed; a modern higher-end smartphone. That solution satisfied the criteria laid out in the following ways.

Due to recent advances in camera technology, modern "flagship" phones have more than enough image quality for producing quality videos, even in low light, especially as the video stream would be compressed prior to transmission anyway. Smartphones by their very nature are made to communicate, both over WiFi and 3/4/5G networks. If a large enough phone is used, the display should be more than capable of relaying visual information back to the assistant. Smartphones are battery-powered and can even be charged while being used through a powerbank, which could in theory provide indefinite usage time on the move. Many of the premium phones also come with waterproofing (IP67/68), which would allow them to be frequently and thoroughly cleaned without issues.

While not precisely cheap, a high-quality smartphone still probably costs less than any of the other proposed solutions and might even be available at the slaughter facility already, in someone's pocket. Smartphones are also available from almost every electronics vendor, making them very simple to replace or upgrade if need be. New models of smartphones boasting improved specifications over the previous generation are brought to market often on a yearly basis. Competition between brands and platforms is steadily pushing development forward. Because of this quick cycle-time and improving specifications, replacing a device should be a very simple process, akin to "grabbing the first best option".

Software designed for smartphones is easiest to distribute on one of the market places for apps (AppStore or Google Play being the largest), and when published is available for any device with access to that marketplace. This means that it would be very simple to install augmented reality software on any phone designated for use in remote meat inspections, by simply opening up the marketplace and installing it.

Naturally, every device that captures the user's attention is a potential risk in a hazardous environment. However, using a smartphone with a display that is comparatively small and placed at arm's length from the user should in theory lead to a rather small portion of the overall field of view being obscured. This should enable a very easy focus shift to the rest of the environment, compared with *e.g.* a head-worn display, which would need to be moved out of the way.

During PM inspections, the assistant would require uninterrupted use of both hands for gripping and performing knife work. By mounting the phone on the back of the user's dominant hand in the present case, free usage of both hands was retained, while still being able to see the display of the phone for augmented reality communication and managing the device (Figures 3 and 4). This also enabled the movement of the camera irrespective of the assistant's body (to a certain degree), meaning carcasses could be filmed in close-up without having to move right up against the material or crouch to a lower position.

### 4.1.3 The software

In order to perform the remote inspections, software capable of transmitting live video was required. Since use of augmented reality was an integral part of this PhD project, this narrowed down the list of potential candidates.

After exploring the market, the Swedish company XMReality was deemed to be a well-suited, if not the only, supplier of a software combining video-calls with augmented reality functionality. Their software, designed primarily to assist in technical repair and maintenance, allowed a remotely located "guide" to superimpose an image of their hand, or other tool or drawing/marker, onto the video stream, in order to directly show the user how to perform a task, or where to perform it (Figure 2).

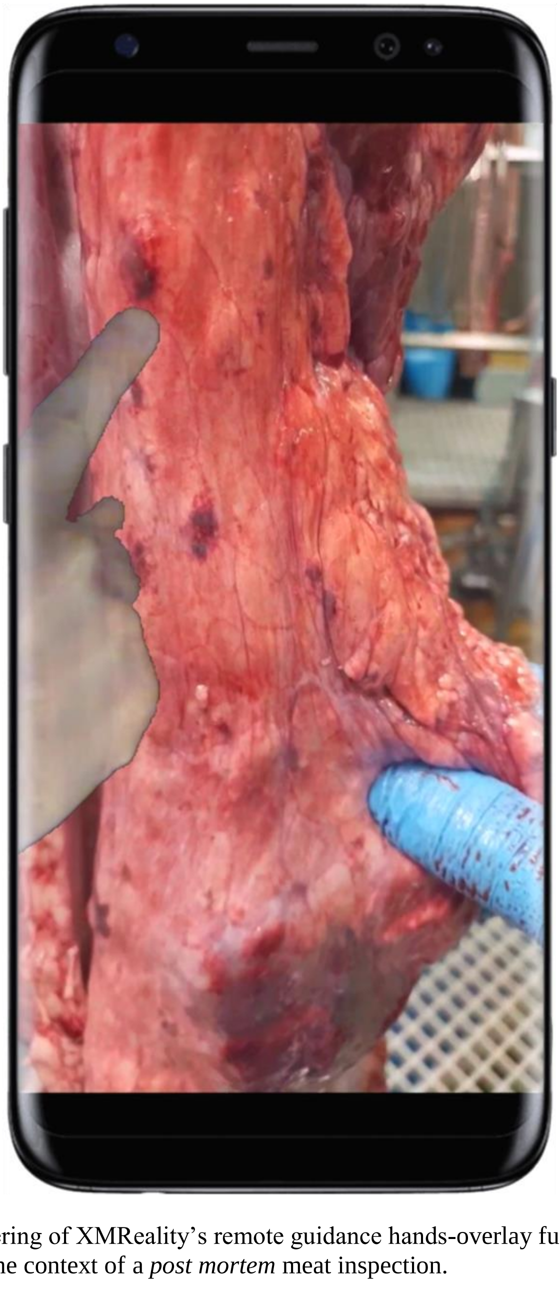


*Figure 2*. Rendering of XMReality’s remote guidance hands-overlay functionality on a smartphone in the context of a *post mortem* meat inspection.

### 4.1.4 The final setup

The final setup for use by the assistant consisted of a smartphone mounted to the back of the hand (Figure 3), together with suitable wireless ear guards. The phone was sourced according to screen size, waterproofing and low-light camera performance. At the time of the trials, the phone which best fitted the criteria was a Samsung Galaxy S9+. The phone was coupled with a pair of Peltor WS Alert XPI Bluetooth ear guards (3M, Inc., Saint Paul, Minnesota, USA), and ran XMReality's application for remote guidance (XMReality Remote Guidance, XMReality AB, Linköping, Sweden). The phone was mounted on the assistant's dominant hand using a hand strap, a generic extender and a phone holder, with protective gloves underneath and on top (Figures 3 and 4).

The receiving terminal consisted of an 8-core desktop PC running Microsoft Windows. The PC connected to the slaughter company's LAN using an Ethernet connection. It had previously been noted that the software used would connect using the local addresses if both devices were present on the same network, only using the internet connection for authentication purposes. By placing both devices on the same LAN a theoretically ideal network connection was obtained, where latency and packet-losses should be minimal. This would allow, again theoretically, perfect transmission of the video stream, which would remove one source of error from the evaluation.

*Figure 3*. Hand mount for smartphone.

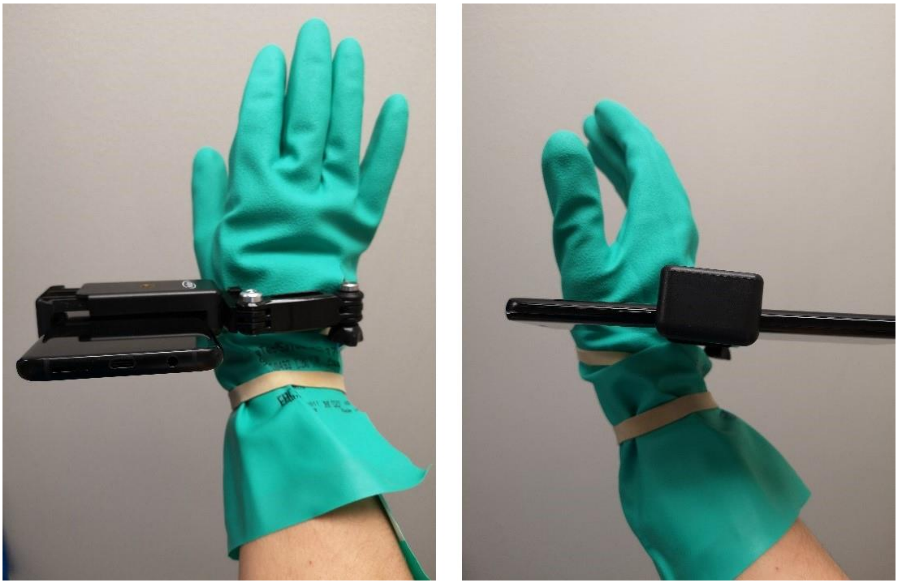


*Figure 4*. Smartphone placement over the back of the hand.

Mounting the smartphone on the back of the hand allowed for free movement of the camera, while the assistant retained the use of both hands, and still kept the display in sight at all times. A more suitable solution would perhaps be use of an external camera that could be moved independently from the display, but that solution was not supported by the Android version of XMReality remote guidance.

The phone was mounted using hardware from GoPro’s system for mounting its action cameras. The hand mount was worn on top of a nitrile glove, and placed at a 90-degree angle relative to the back of the hand (Figure 4). This placement centred the camera roughly over the user’s thumb, which meant that when cutting, the blade of the knife was visible directly in the centre of the image (Figures 5 and 6). By twisting the wrist, the camera could be oriented either horizontally or vertically, in order to capture either a wide or a tall image (Figures 5 and 7). The image on the receiving terminal automatically followed the rotation, making sure that ‘up’ was always ‘up’ on the video.

Using this type of mounting hardware was deemed to fulfil the requirements of a simple and easily replaceable solution, while remaining functional and hygienic. The all-plastic design of the mounting hardware made it easy to clean and disinfect.

The solution during use is demonstrated in Figures 5-7, where the images correspond to the assistant’s view when performing inspections.

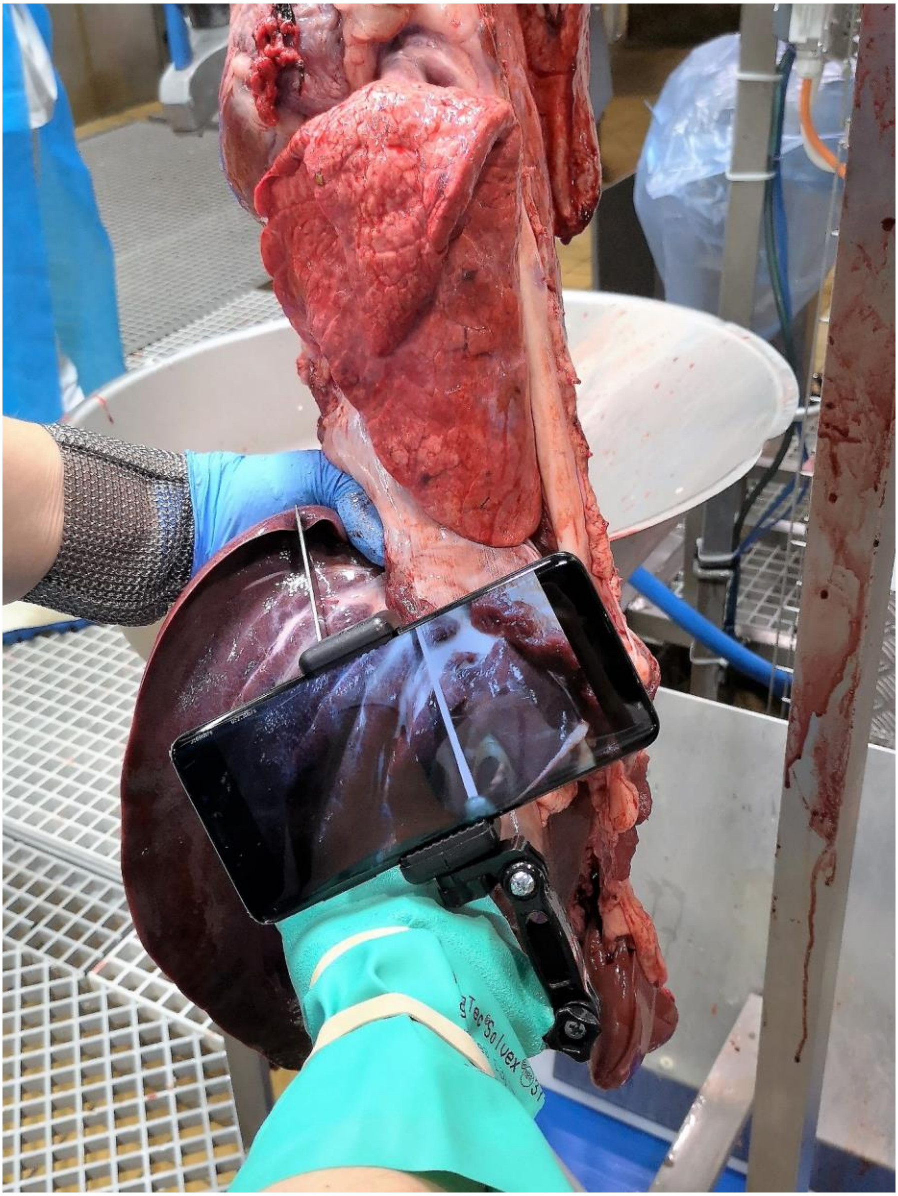


*Figure 5*. Remote veterinary *post mortem* inspection in action, assistant’s view.

*Figure 6*. Remote veterinary *post mortem* inspection in action, assistant’s view.

*Figure 7.* Remote veterinary *post mortem* inspection in action, assistant's view.

#### 4.1.5 Evaluating the solution

The combined software and hardware solution was evaluated during 400 in-depth veterinary PM inspections and 400 AM inspections in spring 2019. The criteria evaluated were subjective ease of use, battery life, connection quality, and maintenance and cleaning. The connection quality was evaluated for each of the 400 inspections by asking both users of the remote solution (the assistant and the OV) to record any technology-related disruptions in communication.

Cellular bandwidth was also tested for three of Sweden's large telecom operators. Testing was performed at the location where veterinary inspections were performed, and each telecom operator was sampled five times. The smartphone intended for use in data collection was used during testing (Samsung Galaxy s9+. Samsung, Inc., Seoul, South Korea), and measurements were taken using the app 'Speedtest by Ookla' (Ookla, LLC, Seattle, Washington, USA). All three telecom operators were tested against the same server, geographically close to the measurement site.

## 4.2 Studies II-IV (Papers II-IV)

### 4.2.1 Training and pilot study

Two veterinarians with several years of prior experience as OVs, hereafter referred to as OVA and OVB, participated in the research studies. While not strictly performing the function of OV at the facility during the studies, they possessed the necessary qualifications. Both were assumed to be proficient in their role as OV and were assumed to be equal in their knowledge, since they possessed similar experience. In an attempt to solidify this assumption, both OVs underwent a one-day theoretical PM inspection course designed by the Swedish Food Agency. The course was aimed at equalising their assessments and giving a refresher in how to judge various findings.

In addition to this course, both OVs performed a three-day pilot study in November 2018, during which they both worked on-site at the same facility, inspecting the same animals and carcasses and recording their findings. This was done to gain an understanding of any potential differences in judgement between the two. During these three days the OVs inspected every carcass detained for further inspection by OA (19 in total), and 24 groups of live animals (with 15-23 animals per group). The OVs discussed and compared their findings and judgements after each observation.

### 4.2.2 Study II - Method vs. method

Remote inspection and on-site inspection were compared in a study conducted at a commercial slaughterhouse, during normal operations, on animals arrested for further inspection by the facility's OA.

A decision was made to base the evaluation on kappa-based statistics, comparing on-site to remote inspections. Because of this, both methods had to be used on the same carcasses and organs. The only feasible alternative was for two persons to perform the inspections with one method each, one after the other on the same material (Figures 8 and 9).

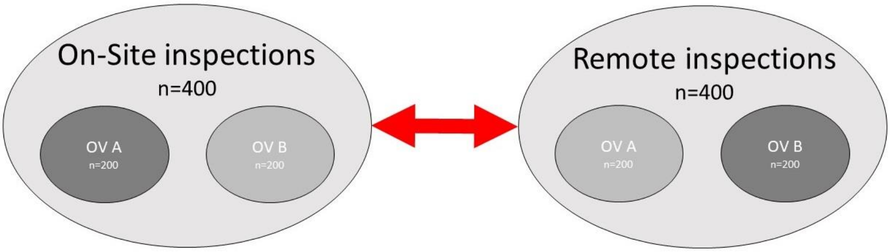


*Figure 8.* Schematic representation of comparisons between two methods (on-site, remote) for veterinary inspections at slaughter, performed by two official veterinarians (OVA, OVB).

A total of 400 PM inspections, evaluating pig carcasses and organs (hereafter referred to only as "carcasses"), arrested for further inspection, and AM inspections of 400 groups of live animals, were performed. The groups of live animals were pens of pigs in the slaughterhouse's lairage area.

*PM inspections*

Between around 8.30 h and 14.30 h during 27 working days, the two OVs conducted their inspections. One OV performed inspections on-site at the slaughterhouse, and one OV worked with a smartphone-equipped assistant on-site to perform the inspections remotely. The OVs inspected 400 carcasses arrested for further inspection by the OA, employing one method of inspection each. The OVs switched methods three times during the study (performing approximately 25, 100 and 75 inspections with both methods), making a total of 200 inspections with each. Between four and 22 carcasses were inspected per day.

In order to introduce a negative control group into the PM material, the OAs at the facility were instructed to arrest a number of carcasses each work shift (1.5 hours) that, according to their judgement, displayed no findings. The number of these “false arrests” was predetermined as a gamma-distributed pseudo-random number between zero and seven per work shift, and given to the OA in advance. The OA wrote down which running numbers had been arrested in this fashion.

The OVs were informed that there would be a number of false arrests, but had no knowledge of the actual numbers per shift and obviously not which carcasses they were. Since carcasses are not normally arrested for further inspection without cause, this was necessary to allow the OVs the possibility of concluding the inspection without finding anything, instead of continuing the search indefinitely.

The OVs recorded their PM findings according to a modified version of the standard routine for recording findings at slaughter established by the Swedish Food Agency (2014) (Table 1). The modifications included addition of a code for kidney lesion, which is normally not recorded in pigs, to denote renal cysts or septic abscesses in the kidneys, and a code for “no findings”. In addition, all findings were recorded, regardless of size, meaning that very small lesions which under normal circumstances could be considered “too small to care about” had to be noted as well.

Table 1. *Codes for findings at* post mortem *inspection according to modified instructions used by the Swedish Food Agency (2014)*

| *Code* | *Finding* | *Code* | *Finding* | *Code* | *Finding* |
|---|---|---|---|---|---|
| 06 | Atypical mycobacteriosis | 40 | Old injury | 72 | *Actinobacillus* pleuropneumonia |
| 18 | Erysipelas | 42 | Recent injury | 76 | Pleuritis and/or endocarditis |
| 19 | Systemic infectious disease | 46 | Abnormal odour | 78 | Pleuritis and peritonitis |
| 26 | Tumour | 48 | Emaciation | 84 | Parasitic liver lesions, “white spots” |
| 30 | Abscess | 52 | Other finding | 88 | Other liver lesions |
| 32 | Arthritis | 56 | Kidney lesion | 999 | No findings |
| 34 | Abnormal appearance | 58 | Tail lesion | FA | Perceived falsely arrested |
| 36 | Pale-soft-exudative | 62 | Swine enzootic pneumonia | TC | Totally condemned |
| 38 | Fatty liver | 64 | Other pneumonia | | |

Based on their findings, each OV classified a carcass as either falsely arrested, meaning it would not normally have been arrested (this indicated that the carcass was from the negative control group) or, if not (*i.e.* a true arrest), whether the carcass should be totally condemned or not.

All remote inspections were recorded on the receiving terminal. Since the two OVs inspected the same material, and since in-depth veterinary inspections sometimes require incisions to be made in the material, it was deemed important to minimise the effect that the two inspectors could have on each another. The assumption was that if there was a difference between the methods, it is likely that the on-site inspection was correct and that the remote inspector would detect fewer findings. Thus it was deemed a risk that the on-site inspector could guide the remote inspector to a finding by *e.g.* performing an incision in it, but not the other way around. Due to this, the on-site inspections were split into two parts, where a purely visual inspection was first performed, taking mental note of what further examinations would be performed, after which the remote inspection was carried out, and lastly the on-site inspector returned to perform any palpation and incisions deemed necessary. This allowed the remote inspector to always have untouched material to start with and prevented any hints through the on-site inspector's behaviour. The remote inspection call was not initiated until after the on-site inspector had finished with the first carcass half, and the on-site OV moved away in order not to see or hear what the remote inspection duo (OV and assistant) did or said.

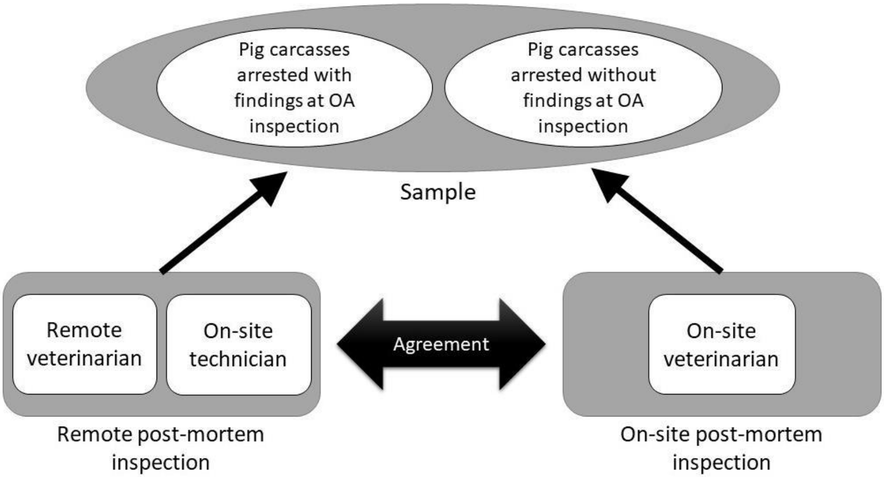


*Figure 9.* Schematic representation of the inspections performed, both on-site and by the remote inspection pair, on carcasses arrested for further inspection by the official auxiliaries (OA).

### *AM inspections*

*Ante mortem* inspections were carried out in much the same way as PM inspections. One OV performed inspections in the lairage area and one worked with the assistant, who relayed video of the live animals. Inspections were performed between 9.30 h and 16.00 h over nine working days. Because pigs at slaughter were housed in groups and since both OVs had to inspect the same animals, it was concluded that the inspections had to be carried out at "pen level", rather than on individual animals. This was the only way to allow both OVs to inspect the same animals one after the other without affecting the normal operations of the slaughter company. Thus the two OVs inspected 400 pens of animals, with between 10 and 36 animals per pen. The number of groups inspected varied between 15 and 62 per observation day.

During the inspections the OVs did not disturb, manipulate or otherwise interact with the animals. The inspections were carried out by the on-site inspector first, followed by the remote inspector.

The OVs checked for signs of nine major findings, according to Table 2, and the number of animals in the group with each finding. Since recording of findings is not normally performed at AM inspection, the list of findings was developed based on personal experience of the OVs, *i.e.* what they thought could occur in the animals. In addition to the code-based findings, the OVs also recorded whether or not the animals were approved for slaughter based on the findings and whether the animals appeared to suffer from animal welfare-related issues or epizootic disease.

Table 2. *Findings at* ante mortem *inspection*

| *Finding* | *Finding* | *Finding* |
|---|---|---|
| Lameness | Wound/trauma | Other finding |
| Tail injury | Erysipelas | Animal welfare issue |
| Coughing | Impaired general condition | Epizootic disease |
| Hernia | Dead | Rejected from slaughter |

### 4.2.3 Study III – Intragroup agreement

Even though the assumption was that the two OVs in study II were equal in their knowledge and would assess findings similarly, this could not be conclusively proven. Since all remote inspections in study II were recorded, it was decided to use these recordings to attempt an evaluation of agreement within a larger group of OVs performing inspections on video material.

Nine OVs were selected by the Swedish Food Agency to participate in the study. These OVs were each given a USB thumb-drive containing all 400 recorded remote inspections (with both video and audio tracks intact), along with detailed written instructions on how to perform the inspections and record any findings, with examples detailing modifications to the normal routines. Findings were recorded according to the same instructions and using the same codes as in study II. The OVs were allowed to pause and rewind the video as they saw fit, but could not return to a previous video once it was done.

Agreement was compared within the group of OVs (Figure 10), using multi-rater variants of Cohen's kappa and its derivatives, including a new measurement of prevalence-adjusted multi-rater agreement, developed during the data analysis, called Almqvist's PABAK.

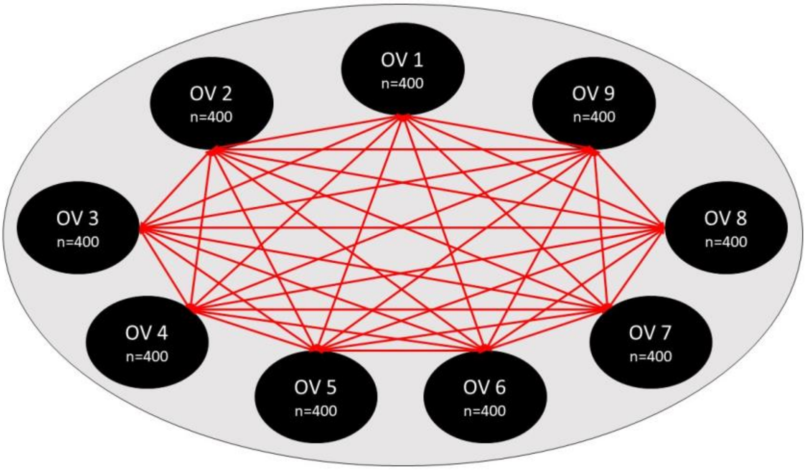


*Figure 10*. Schematic visualisation of intra-group comparisons between nine official veterinarians (OVs) performing inspections on pre-recorded video material. The red arrows represent comparisons; all OVs were compared with one another.

In addition to the intra-group agreement detailed above, the results from each OV's inspection was compared against the on-site inspection data collected during study II (Figure 11). These results were then averaged across all nine OVs, into mean estimates of agreement between on-site inspection and inspection performed on video-based material.

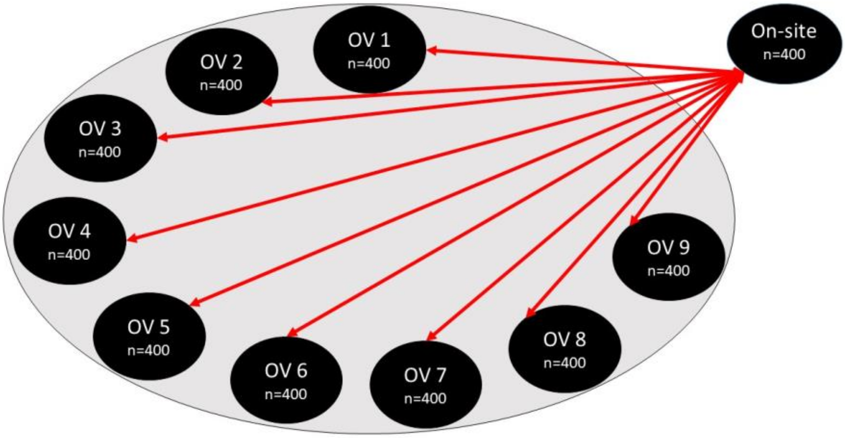


*Figure 11*. Schematic visualisation of intra-group comparisons between nine official veterinarians (OVs) performing inspections on pre-recorded video material. The red arrows represent comparisons; all OVs were compared to records from on-site inspections in study II.

### 4.2.4 Study IV – Intra-rater, inter-method agreement

Since Study III showed marked variation in agreement between OVs, it was deemed relevant to examine how each of the original raters, OVA and OVB, performed while each using two different inspection methods on the same material. By letting both OVs inspect the recorded videos from the other person, two datasets where an OV had inspected the same material both on-site and through recorded video were created (Figure 12).

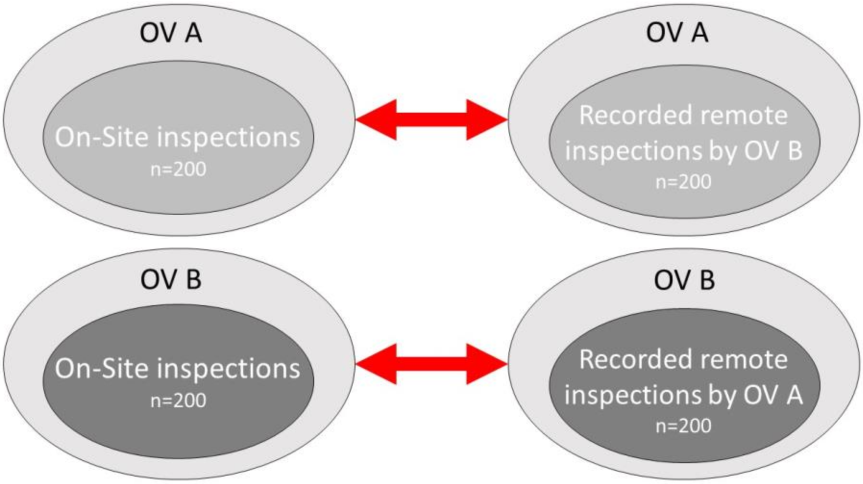


*Figure 12*. Schematic visualisation of agreement between the same two official veterinarians (OVA, OVB) performing inspections on pre-recorded video inspections, and on their own assessments from on-site inspections.

Each of the two original OVs reviewed the other's inspection videos 2-3 months after completing the PM part of study II. The video-files were played back, and the inspections were carried out according to the instructions in study II, which the OVs were familiar with. Pausing the video, rewinding and watching again were allowed, but the OVs were not allowed to return to a previous video once the findings were recorded.

## 4.3 Agreement measures and calculations

In studies of rater agreement, the objective is usually to compare two persons to one another and try to ascertain how equal they are in their assessments. In literature, two terms often feature: interrater agreement and interrater reliability. The two are often used interchangeably, and while there are finer points separating the two (Gisev *et al.*, 2013), in this thesis the term interrater agreement, or simply agreement, will be used throughout.

In its most simple form, this agreement calculation is done by binary classification of a certain finding (present or not present). There are various ways in which this measurement of agreement can be calculated. The simplest is what is known as percentage agreement, *i.e*. the simple proportion of how many items out of the total are rated the same by both raters.

Since humans are not perfect raters and there are only two choices, if a rater does not know for sure they will likely make a guess. This can lead to agreement even though one or both raters did not know how to classify an object. To correct for these possible chance agreements, another measurement is used, namely Cohen's kappa (Cohen, 1960). Cohen's kappa takes this random chance agreement into consideration and adjusts the measure of agreement accordingly. Byrt *et al.* (1993) showed that Cohen's kappa tends to produce lower agreement if the prevalence of the finding in question is low, which led to them creating prevalence- and bias-adjusted kappa (PABAK). PABAK is intended to be a representation of agreement in a theoretical population with 50% prevalence of the finding in question. If the true prevalence in the population is 50%, PABAK and Cohen's kappa should produce the same value.

Cohen's kappa, and its close relative Scott's Pi (Scott, 1956), have also been developed and generalised into variants which can handle more than two raters, *e.g*. Light's kappa (Light, 1970) and Fleiss' kappa (Fleiss, 1970), among others.

In studies II-IV, all three of these measures of agreement were calculated. For cases with two raters, Cohen's kappa and PABAK were used, in addition to the percentage agreement. In the first part of study III, where agreement was compared within a larger group, Fleiss' kappa and Light's kappa were both used, along with the multi-rater variant of PABAK developed during this thesis work, *i.e*. Almqvist's PABAK. By applying the logic of Light's kappa to Byrt *et al.*'s PABAK, *i.e*. taking the average value of all pairwise PABAK values within a group, this new measure of reliability was created:

$$Almqvist's\ PABAK = \frac{\sum_{i=1}^{N} PABAK}{N} \qquad \text{(equation 1)}$$

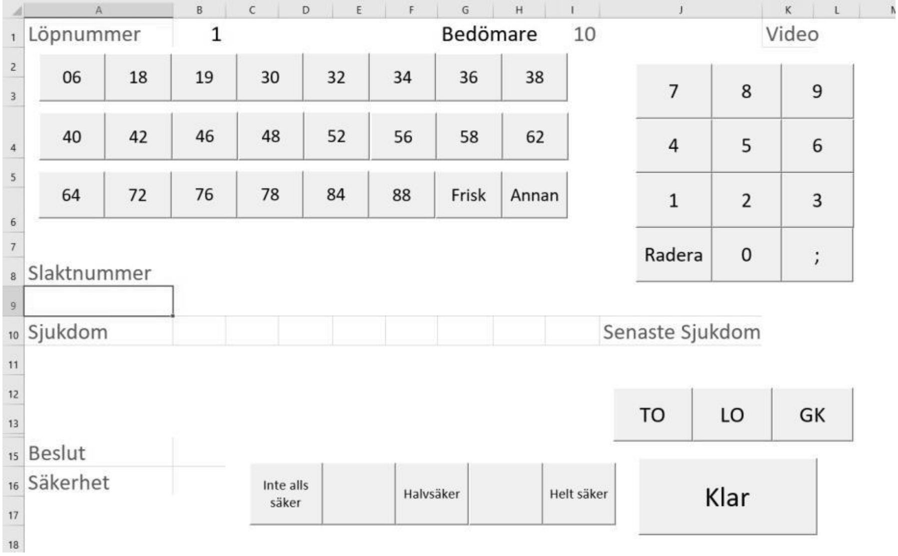
where *N* is the possible number of pair-wise comparisons among *n* raters:

$$N = \binom{n}{2} = \frac{n!}{2!(n-2)!} \qquad \text{(equation 2)}$$

This should in theory produce a prevalence- and bias-adjusted measure of agreement for a group of raters larger than two.

These three measures of agreement were calculated for each of the 26 codes, using all 400 observations except in the case of the code TC. For TC, only the subsets where all raters compared agreed that the carcass was not FA were used, since an FA carcass exclusively cannot be TC.

Data collection was performed using an interactive Excel form coded in Microsoft Visual Basic (Microsoft Corp., Redmond, Washington, USA) (Figure 13) and analyses were performed in R (R Core Team, Vienna, Austria). The R module ‘EpiR’ (Stevenson, 2020) was used for Cohen’s kappa and PABAK, and ‘DescTools’ (Signorell, 2020) for Fleiss’ and Light’s kappa. Almqvist’s PABAK was calculated using a self-written R-function which relied on Cohen’s kappa values from EpiR.



Löpnummer 1

Bedömare 10

*Figure 13.* Interactive Excel-form coded in Microsoft Visual Basic in order to emulate the touch-interface often used to record findings during *post mortem* inspection at slaughter.

## 4.4 Economic viability of remote meat inspection

The mathematical relationship for the costs of meat inspection was assumed to be a multivariable linear function of the form:

$$K \approx f(x, y, z \ldots) = abc * x + def * y + gh * z \ldots \qquad \text{(equation 3)}$$

where K is the cost of inspection, x, y, z… are variables such as number of inspected animals, distance to travel to the facility, inspection time per animal *etc*., and a, b, c, d… express the cost associated with a change in each variable, *e.g*. costs of travel, cost per hour of personnel, inspection time per animal *etc*.

Since the cost terms were not known, they were assumed according to educated guesses or, in the case of inspection time and inspection time factor, taken from study II (Table 3).

Table 3. *Constants used in equation (3) to calculate the costs of meat inspection at a small-scale slaughter plant*

| **Factor** | **Value** | **Units** | **Symbol** |
|---|---|---|---|
| Personnel cost | 500 | SEK per hour | $k_p$ |
| Car cost | 25 | SEK per 10 km | $k_c$ |
| Distance to facility | - | km | $d$ |
| Travel time | - | Minutes | $t_t$ |
| Inspection time | 1.8 | Minutes per animal | $t_i$ |
| Number of inspected animals | - | - | $n$ |
| Inspection time factor | 3 | Number of times longer inspections at remote inspection | $f$ |

The final equation for the cost of meat inspection at a remote small-scale facility was assumed to be:

$$K \approx \frac{k_p}{60} * f * t_i * n + 2 * \frac{k_c}{10} * d + \frac{k_p}{60} * 2 * \ t_t \qquad \text{(equation 4)}$$

Because travel time is a function of distance, assuming an average velocity of $v$ km/h, $t_t$ can be rewritten as $d*60/v$ and equation 2 can be shortened and simplified to:

$$K \approx \frac{k_p}{60} * \left(t_i * n + 2 * \frac{60}{v} * d\right) + 2 * d * \frac{k_c}{10} \qquad \text{(equation 5)}$$

# 5. Summary of results

## 5.1 Technological solution (Paper I)

### 5.1.1 Handling and usage

The assistant reported that both software and hardware were easy to use and understand. However, use of a steel safety glove on the non-dominant hand (used for gripping), combined with the nitrile and rubber gloves used for hygienic reasons, resulted in an inability to manipulate the touch screen of the phone, even when the sensitivity was increased using the so-called glove mode. This was expected, and is due to the nature of modern capacitive touch screens (Bae & Hong, 2013). Since no input was required other than launching the app and initiating the remote guidance session, using a small stylus pen mitigated these issues completely. The device was also easy to clean and maintain, since the only maintenance required was charging the device daily.

After a few days of use the assistant complained about pain and stiffness in the shoulder and upper back. On shifting the positioning of the hand and performing the filming of the material in such a way that the phone was never held above shoulder-level, these problems subsided. Not working above shoulder level is ergonomically sound, since it minimises the risks of injuries to the shoulder and neck (Kroemer, 1989).

The augmented reality overlay was reported to function well, and was easy to see for both the assistant and remote OV. However, it was noted that this function appeared to be used less over time. In the beginning of the study, the overlay was used both to target a finding for examination and to visually describe how to perform both palpations and incisions. Towards the end, the hands-overlay was mostly superseded by the simple cursor, and primarily used to indicate to the assistant which finding to focus on. It was noted by both OVs that the assistant became increasingly proficient, and sometimes spontaneously suggested which findings to examine further. This points towards a learning experience for the assistant, and might very well explain why the more advanced teaching tools were used less over time; they were simply not needed when the assistant had learned how to perform the practical handiwork and got to know the OV's style of inspection.

Since the entire hardware solution was mounted on the back of the assistant's hand, it was simple to move it closer to the slaughter material, essentially zooming in closer on a finding. On doing this, even a small finding still occupied a significant portion of the image, which in theory should give more than enough detail to evaluate it. A disadvantage of the hand mounting was that the assistant continually needed to shift focus between the display and the carcass, since filming had to be performed using the display of the phone to make sure everything was visible. This impaired the direct eye-to-eye view for the assistant, which could in theory lead to slight difficulty when receiving augmented reality instructions on the display, since the instructions would then have to be 'transposed' onto the material, correcting for the slightly different angle compared with eyesight. However, this did not appear to be a major issue.

### 5.1.2 Cellular communications

Results from cellular bandwidth measurements are presented in Table 4.

Table 4. *Average bandwidth and latency over 4G, taken over five consecutive measurements, for the three largest cellular providers in Sweden*

| | *Telia* | *Tre* | *Tele2/Comviq* |
|---|---|---|---|
| *Download (Mb/s)* | 9.75 | 17.44 | 71.10 |
| *Upload (Mb/s)* | 1.45 | 3.51 | 6.67 |
| *Latency (ms)* | 40.8 | 36.4 | 26.0 |

This type of bandwidth test works by sending data packets to a receiving server and back, for a fixed time. The more data that arrive at the server during that time, the higher the bandwidth. The value received is thus merely an average number of the bandwidth during that measurement time. Since cellular reception fluctuates, the test does not give any information about *e.g.* the highest and lowest bandwidths that occur during the measurement. Thus there is still the possibility of momentary dips below what can be considered acceptable for video communication.

### 5.1.3 Comparison of transmission methods

Video transmitted over the internet is almost always subject to compression. The degree of compression depends on the available bandwidth, which for live-streamed video is continuously monitored by the software. Video quality is adjusted on the fly to fit this available bandwidth. In Figures 14-16, visually similar still images from three video files are presented, one transmitted over 4G, one over WiFi to a local receiver (through a LAN) (both using XMReality Remote Guidance), and one from a video recorded locally on the smartphone and not transmitted.

It is apparent that the image quality over 4G leaves much to be desired (Figure 14). There is also an obvious difference between the LAN-transmitted video (Figure 15) and that straight from the camera (Figure 16), but this difference is less pronounced. Allowing for higher bandwidth to be used in transmission of the video should decrease these differences, assuming a strong enough connection.

*Figure 14*. Still image from remote inspection carried out over a 4G cellular connection.

*Figure 15*. Still image from remote inspection carried out over a local network connection.

*Figure 16*. Still image from untransmitted video emulating remote veterinary inspection.

### 5.1.4 Disruptions

Use of a WiFi for the smartphone, with the receiving terminal located on the same LAN, should in theory allow for optimal networking performance given the devices used, but some disturbances in communications were observed (Paper I). These were either a lowering of the image quality of the call or the call dropping. If a disturbance occurred, the users waited for it to subside (which usually happened within a couple of seconds) or, in event of call dropping, another call was made. In a few cases the lowered quality did not restore itself, and the call had to be manually dropped and re-dialled, upon which the quality was restored. Since PM inspections are carried out in a somewhat standardised sequence (one organ at a time), this had no real impact on the inspection, since it could easily be resumed from the same point, but nonetheless caused significant frustration for the remote OV, especially when multiple disruptions occurred during the same inspection.

The number of disturbances per call appeared to increase over time, and toward the end of the study there could be up to 20 in a single inspection (Figure 17). However, disturbances appeared to rather evenly distributed in work passes during the day (Figure 18). During inspections with sufficient quality, the smartphone was constantly transmitting somewhere between 2.7 and 3 Mbit/s. This is in line with the hard-coded bandwidth cap of the software. When quality disruptions occurred, it was observed by the assistant that the smartphone was not transmitting at the full 3 Mbit/s, but rather at a much lower figure, dipping towards 0.4 Mbit/s or lower.

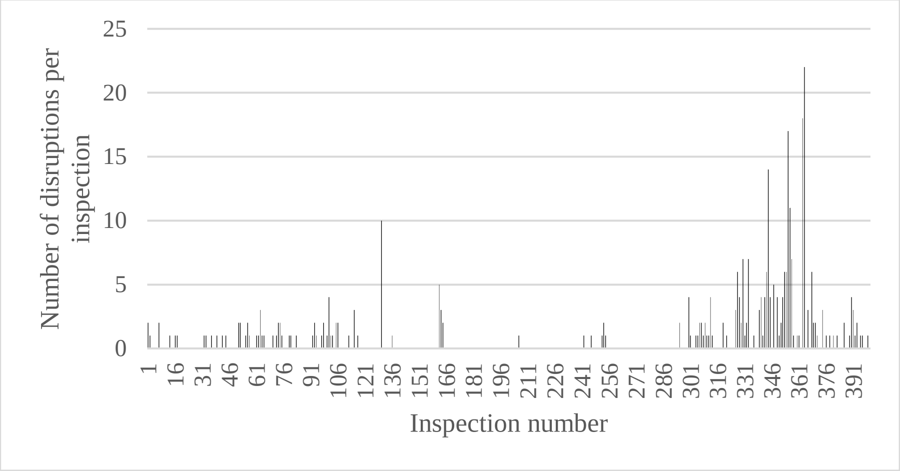


*Figure 17*. Call disruptions reported by the remote assessor for each inspection number (*n*=400).

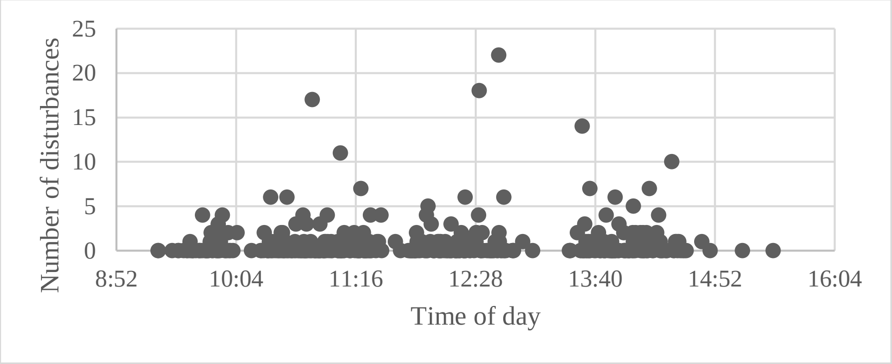


*Figure 18*. Scatter plot of number of call disruptions reported by the remote assessor, sorted by time of day (*n*=400).

## 5.2 Remote inspections (Papers II-IV)

### 5.2.1 *Ante mortem* inspections

All agreement results from the AM part of both the pilot study and study II were inconclusive and all AM inspections were therefore omitted from subsequent analyses, and the results are not presented.

### 5.2.2 *Post mortem* inspections

Codes 18, 38 and 78 (erysipelas, fatty liver and pleuritis and peritonitis, respectively) were not observed during any of the studies, and were omitted from the results. The prevalence of findings during study II are presented in Table 5.

Table 5. *Prevalences of different* post mortem *findings on pig carcasses in study* II.

| *Code* | *Prevalence, %* | *Code* | *Prevalence, %* | *Code* | *Prevalence, %* |
|---|---|---|---|---|---|
| 06 | 1.3 | 42 | 0.75 | 72 | 1.1 |
| 19 | 4.6 | 46 | 0.38 | 76 | 16.0 |
| 26 | 0.38 | 48 | 0.75 | 84 | 10.6 |
| 30 | 5.5 | 52 | 5.0 | 88 | 1.3 |
| 32 | 4.2 | 56 | 14.1 | 999 | 40.5 |
| 34 | 2.5 | 58 | 21.1 | FA | 58.4 |
| 36 | 1.8 | 62 | 11.3 | TC | 23.5 |
| 40 | 0.75 | 64 | 22.8 | | |

The results from the pilot study and studies II-IV are presented graphically in Figures 19-21.

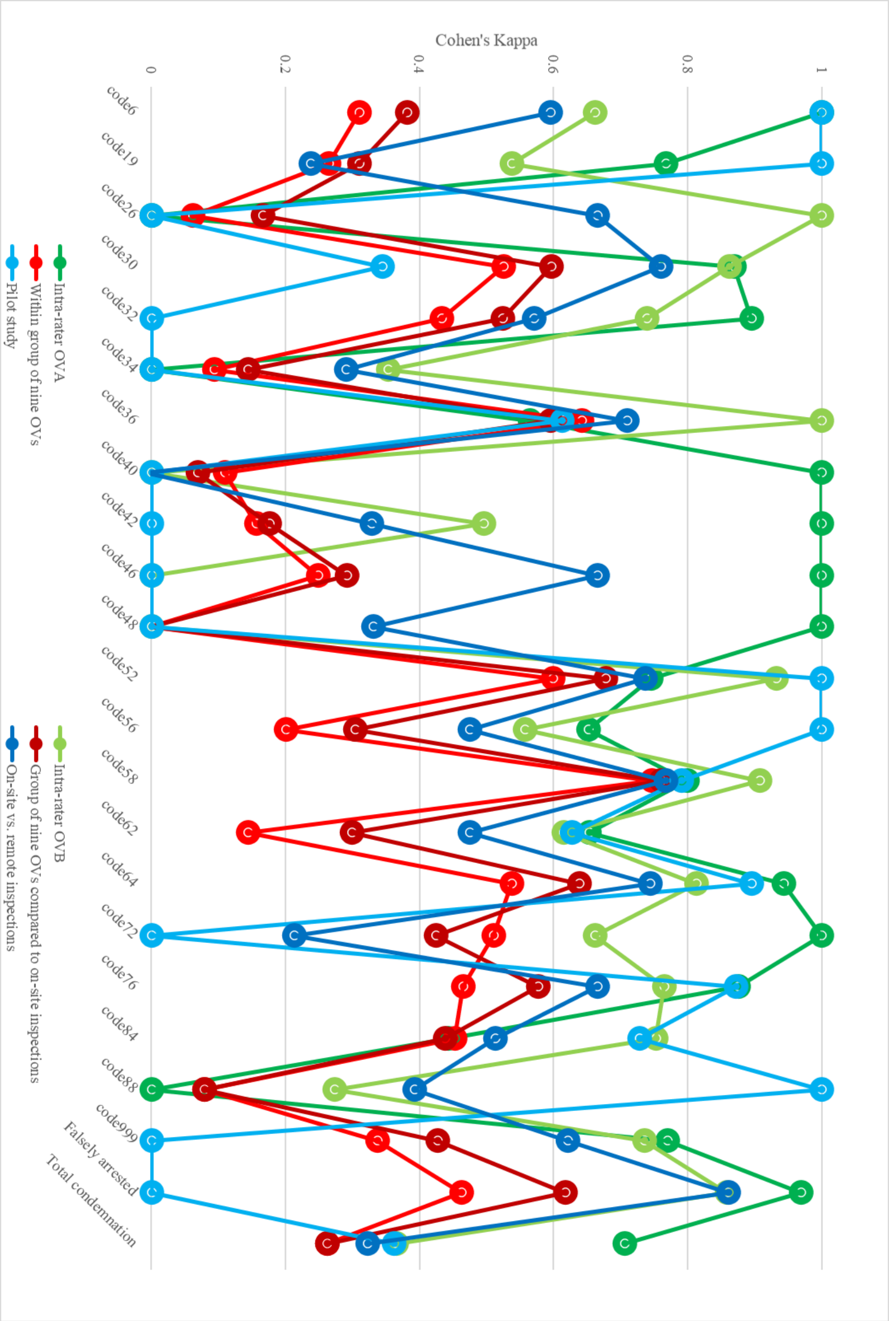


*Figure 19.* Cohen’s Kappa-based agreement between raters in studies II (green), III (red) and IV (blue).

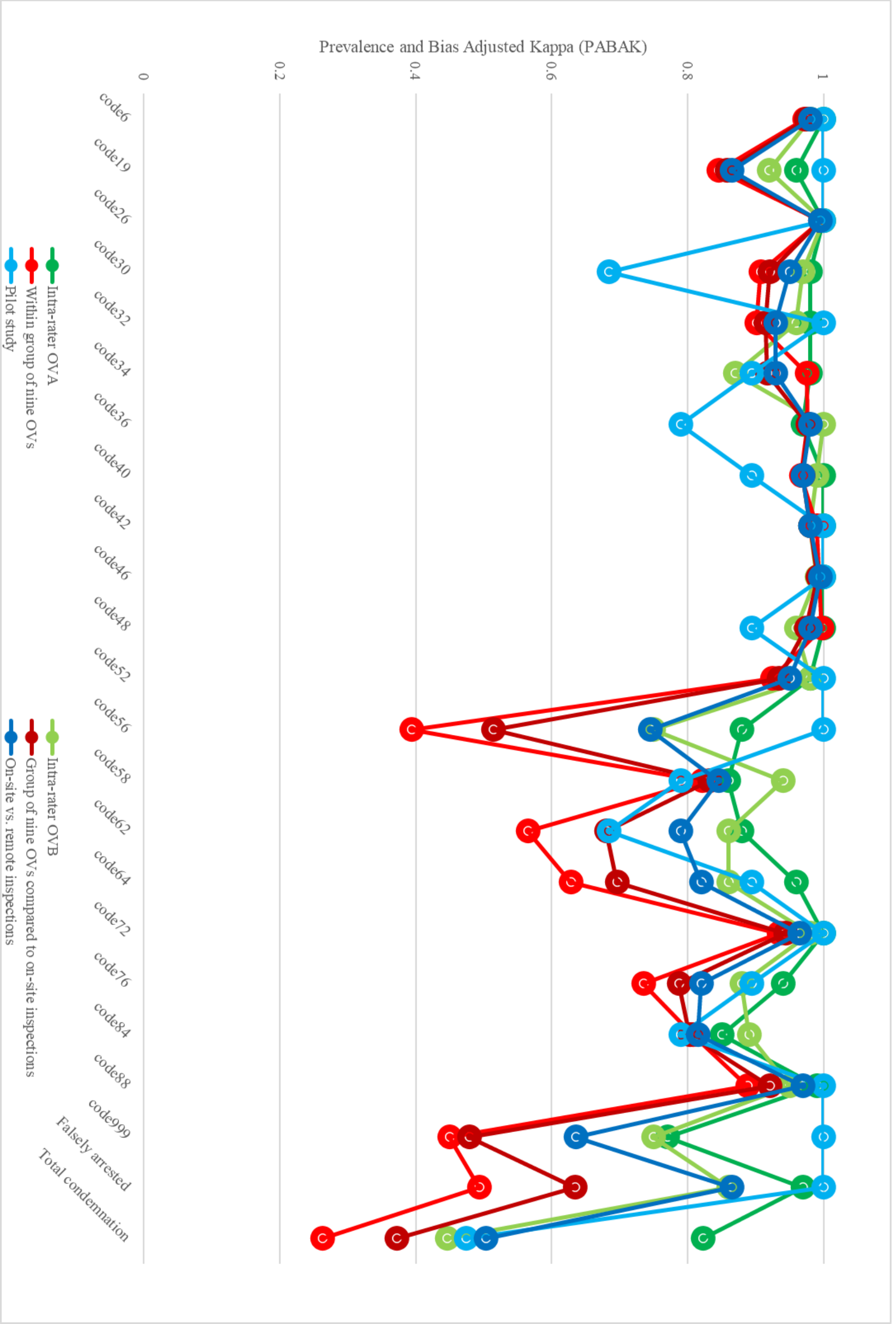


*Figure 20*. Prevalence- and bias-adjusted kappa (PABAK)-based agreement between raters in studies II (green), III (red) and IV (blue).

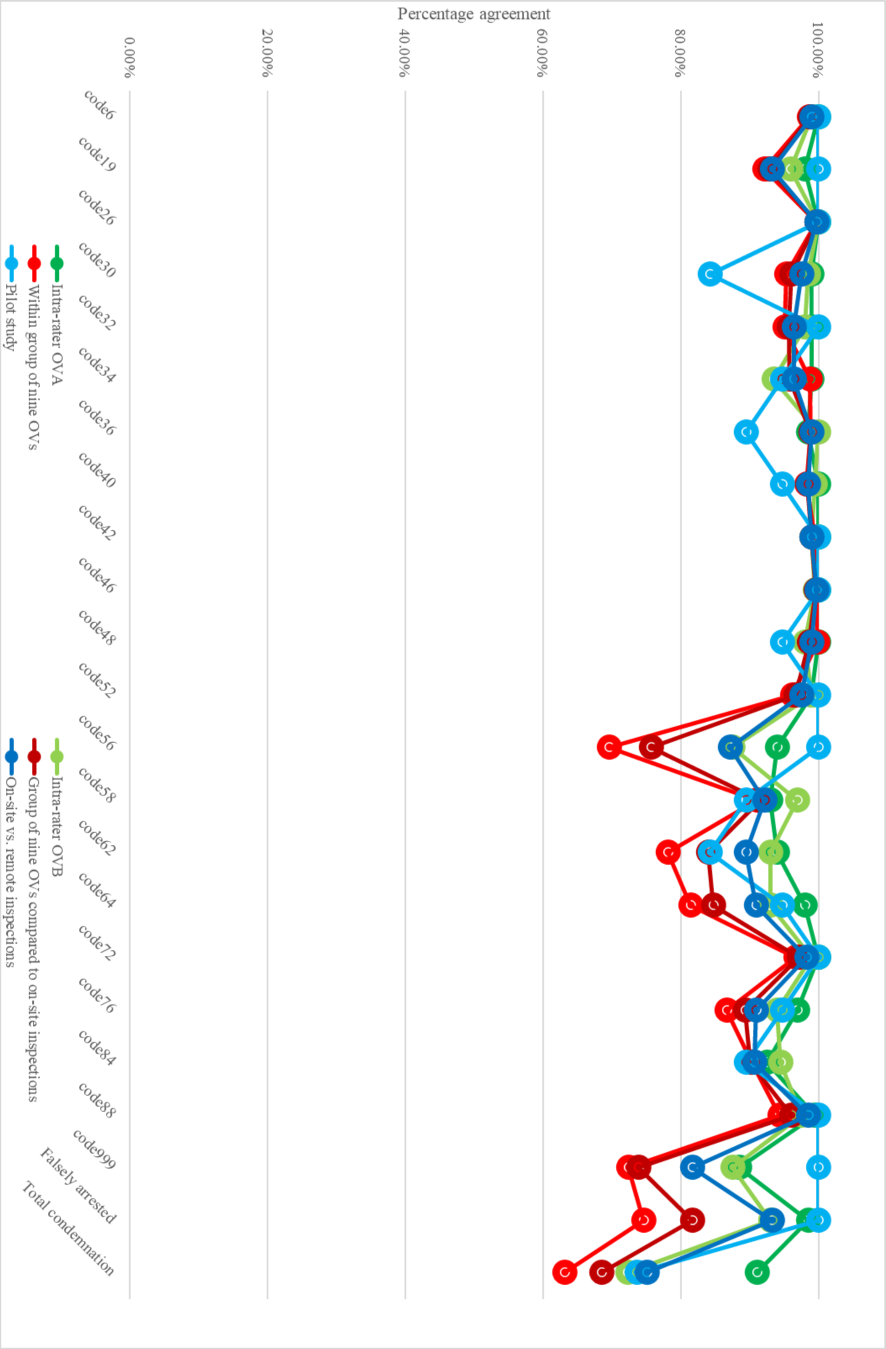


*Figure 21*. Percentage-based agreement between raters in studies II (green), III (red) and IV (blue).

The three different measures of agreement varied slightly, with Cohen’s kappa displaying very large differences between studies and, more importantly, also between lesions. This is likely due to the inherent susceptibility of Cohen’s kappa to low prevalence (Byrt *et al.*, 1993). Since most findings were rare, many values of kappa were lowered because of this and some findings reached extremes at either 1 or 0. These values are likely statistical artefacts, arising from the extremely low prevalence of certain findings.

Artefacts aside, conclusions can still be drawn from the Cohen’s kappa results on comparing the studies. A pattern of correlation between the different rater pairings emerged, with agreement appearing to be highest for the intra-person comparisons, and lowest for the pure intra-group comparisons between the nine OVs. This pattern also appeared to apply for the two other measures of agreement (Figures 20 and 21).

Percentage agreement and PABAK were overall much higher and, while there were differences between findings, they did not display the wild fluctuations of Cohen’s kappa. The same correlation in agreement between the studies seems to apply for these measures too, with the highest agreement within person and the lowest between persons within a larger group.

## 5.3 Cost estimation

Completing the inspection cost equation for both on-site and remote inspection, and then solving the resulting system of equations revealed the breakpoint at which to perform on-site or remote inspection, based on the number of inspected animals, *n*, for which remote inspection is economically viable as a function of the distance *d* to the facility:

$$K_{On-site} \approx \frac{k_p}{60} * \left(t_i * n + 2 * \frac{60}{v} * d\right) + 2 * d * \frac{k_c}{10} \qquad \text{(equation 6)}$$

$$K_{Remote} \approx \frac{k_p}{60} * (t_i * f * n) \qquad \text{(equation 7)}$$

Equating equations 6 and 7, inserting the mean values obtained in this thesis for velocity, personnel and car costs, along with the average inspection time and remote inspection time factor (Table 3), and solving for *n*, produced the following expression:

$$n \approx 0.64 * d \qquad \text{(equation 8)}$$

In a plot of the relationship between distance and number of animals (Figure 22), the shaded area under the line represents the combinations of distance to the facility and number of inspected animals at which remote PM inspections are profitable.

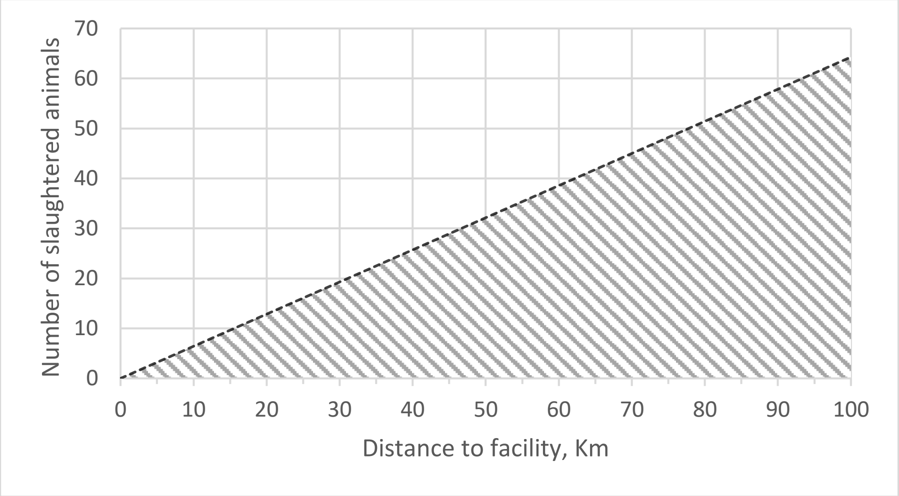


*Figure 22*. Graph of economic viability in remote *post mortem* inspections in terms of slaughtered animals compared with distance to the facility. The shaded area represents cases where it is economically viable to perform remote inspections.

A way to further exemplify the relationship between distance and number of slaughtered animals is to look at two different slaughter plants. One slaughters 8 heads of cattle in a day, and one slaughters 80 sheep.

By entering these numbers into equation 8 we receive a minimum distance of 12.5 km for the cattle facility, and 125 km for the one processing sheep for remote inspections to constitute a viable alternative to conventional on-site inspections.

# 6. Discussion

## 6.1 Technological solution

### 6.1.1 Bandwidth limitations and requirements

When comparing inspection videos transmitted using different connection types, it is obvious that the cellular connection cannot produce sufficiently high image quality to perform veterinary inspections remotely.

Chaabouni *et al.* (2015) previously found the lowest acceptable bit rate for h.264-compressed videos in medical applications to be around 11 Mbit/s, at 1080p60 with constant bit rate and slightly less than 10 Mbit/s using variable bit rate. At 1080p30 these numbers would be closer to 5 Mbit/s. This corresponds to a compression ratio of around 250:1. For reference, various on-demand video services (Netflix, iTunes, YouTube *etc*.) use between 3.5 and 4.8 Mbit/s for 1080p streams (Patterson, 2012), and the larger commercial platforms for live streaming entertainment content (Youtube, Facebook, Twitch) suggest using a bit rate between 3 and 6 Mbit/s for 1080p content.

XMReality remote guidance has a bandwidth limitation of 3 Mbit/s. This puts XMReality's solution slightly below the suggested 5 Mbit/s for 1080p30 video. If all bandwidth were used for the video stream, at the application's stream resolution of 1080p30 this would give compression of an additional 40% over that found by Chaabouni *et al.* (2015). Unfortunately this limitation is programmed into the XMReality software and cannot be changed by the end-user. Further, no information about the encoding parameters could be obtained, which made it impossible to determine how colour depth was handled and which encoding profile the software used. It is possible that the software still utilises the maximum 3Mbit/s if the resolution is set to 720p, which would keep the compression ratio lower, albeit with a halving in resolution.

Whether increased resolution or lower compression is preferable in the context of pathological examinations cannot be determined from these data, and no other study on the subject was found. Berger *et al.* (2015) noted that for general video, when comparing 1080p vs 2160p resolution at fixed lower bit rates, there is a preference by raters for the lower resolution. However, in that case any potential benefits from lower compression would perhaps be lost, at least in partly, due to the 720p video later being up-scaled in software to fit the likely 1080p or higher resolution of the viewing monitor.

Recommendations for future versions of the software would be a developer option to allow for higher bandwidth if desired by the end-user. The use-case of cellular transmission from a remotely situated slaughter facility would put strain on available bandwidth.

Since 5Mbit/s has been suggested to be the lowest limit necessary at 1080p30 for medical applications (Chaabouni *et al.*, 2015), it is reasonable to use this figure as a lowest value that both hardware and software need to achieve. Regarding software, it can be reasoned that a bandwidth cap avoids unnecessary image quality fluctuations since available bandwidth will always vary on any given network, and as soon as a second user transmits data the available bandwidth will drop. Perhaps 3Mbit/s was deemed a level which should almost always be available, and thus the software could always perform close to its maximum. I would argue that if a cap is deemed desirable, setting it much higher than even 5Mbit/s would be good practice. If available bandwidth is a concern, use of the more modern h.265/ codec might be preferable (Ul-Abdin *et al.*, 2016; Suliman Munawar *et al.*, 2017). The application was not designed specifically for the use-case in this thesis, however, and one cannot blame the developer for not taking medical applications into account.

### 6.1.2 Connectivity

Since the application used had a maximum utilised bandwidth of 3Mbit/s, the available bandwidth from all cellular providers should be sufficient. However, Figures 14-16 revealed that there were very clear differences between the main providers. This indicates that bandwidth is not the only important factor, and that the cellular signal most likely fluctuates somewhat.

Due to the live nature of the video stream in the use-case, even very short fluctuations can have a noticeable effect on quality.

From this thesis work alone, no real conclusions on the performance of remote veterinary inspections over 3/4/5G can be drawn, since the only evaluation was performed deep within a large concrete complex and only one attempt was made. As mentioned previously, signal attenuation increases with the number of surrounding walls and the density of their construction. The only conclusion that can be drawn is that remote veterinary inspections over 3/4/5G would likely function *better* in a smaller building, but it cannot be said that they will function *sufficiently*. Results from bandwidth tests indicated no problem at all, but the real-world trial gave a different indication. This is likely due to the inherent weakness of bandwidth tests, which only give the average bandwidth over the measurement period, not the lowest value. Caffery & Smith (2015) concluded that 4G connectivity was an appropriate technology for performing medical consultations in humans. They however noted the importance of assessing the network at the location where the service would be provided. The performance of cellular connections for use in remote veterinary inspections at slaughter would have to be examined in much more depth in order to evaluate this.

Using a hardwired connection is always preferable to wireless. The main issues theorised in a real-world application of the method using cellular connections are signal attenuation from the building itself, poor reception due to rural locations and congestion in the mobile network, which could cause fluctuations in available bandwidth and data packet losses. All these can be mitigated by using a terrestrial-based connection.

Because of the latency involved, satellite-based connectivity for use with remote video inspection can be ruled out. In addition, the technology requires line-of-sight, meaning it cannot be used indoors without network-extending hardware, which would be exceptionally cumbersome to achieve and set up in a mobile solution. Note that future constellations such as SpaceX’s Starlink (SpaceX, Hawthorne, California, United States), which uses satellites in low earth orbit, could reduce the latency to around 20-40 ms (Starlink, 2021), and could thus become a viable alternative to 4G and 5G communication if and when the system is available in Sweden. However, this system requires fixed installation and thus lacks the portability of a cellular connection. Thus the solution might not be feasible for use in the Swedish Food Agency’s regime, but could be an option for the slaughter companies to provide a fixed internet connection on their premises in the event of a terrestrial connection not being available.

### 6.1.3 Disruptions

The most likely explanation for the disturbances observed during the PM part of study II was wireless network congestion. If insufficient bandwidth is available, or the networking hardware handles too many requests at once, transmission suffers. Since the internal structure of the site's networking layout was not known, it is impossible to know the throughput capabilities of the wireless local area network (WLAN), and similarly troubleshooting could not be performed. An unsecured WiFi was used during the study, for practical reasons, and it is likely that this network was discovered over time by other slaughterhouse workers, who perhaps used it for streaming music to their phones or the like. This could explain why the number of disturbances appeared to increase over time (Figure 17).

During the AM inspections, another WiFi was used, secured this time, connecting to another access point, and no disruptions occurred at all. This further points to some kind of networking issues with the wireless network used at PM inspections, rather than the entire LAN of the facility.

If remote veterinary inspections at slaughter are to be implemented, a list of requirements for the technical solution used should be established. The requirements should ideally encompass a performance specification for the connection used and suitable security requirements for information transfer and storage. Although the risk of a third party monitoring or tampering with the video stream in real-time is very unlikely, and the information contained within is likely of no interest to any party with such capabilities, but it is prudent to avoid any information leaks if possible. Establishing a suitable level of security is up to the supplier of the software used in implement remote veterinary inspections. These requirements were not evaluated further in this thesis.

### 6.1.4 Recommendations on technologies

Regarding the technological solution, my advice is to keep things as simple as possible in terms of hardware and software. The user might not be technologically inclined and because of this, less is always more. Remote inspections would obviously require an internet connection of some sort, and I strongly recommend using a terrestrial-based connection if possible. If this is not possible, the connection must be able to sustain a latency of less than 20-30 ms with minimal jitter and as much bandwidth as possible. 3 Mbit/s was deemed sufficient in this thesis, but if software is available that can utilise more than that, it is always preferable. I recommend that if a slaughter facility wishes to employ remote veterinary inspections, it should be required to provide an internet connection which meets these specifications, in much the same way that the legislation requires it to provide sufficient lighting.

## 6.2 Remote veterinary inspections at slaughter

### 6.2.1 *Ante mortem* inspections

Unfortunately, AM inspections could not be evaluated conclusively using the study design in this thesis. Since both veterinarians would need to assess the same material, but separated in time in order to not be influenced by how the other is acting, the dynamic nature of living animals poses a significant problem because expression of disease might not be continuous, *e.g.* coughing, or lame animals lying down. The fact that pigs are housed in groups in slaughterhouse lairage further complicated the comparison, since even continuously expressed problems, *e.g.* an injury, might be masked by movements in the group and the animals shifting and obscuring one another. However, the largest problem with evaluating remote AM inspection is that the health of Swedish pigs is generally very good, with very low prevalence of findings at AM inspections in general. Even if all findings were to present themselves to both veterinarians, the low prevalence would cause any statistical comparison between them to be inconclusive. As stated previously, it is debatable what high agreement really means when it stems almost exclusively from negative cases.

For more conclusive evaluation of remote AM inspections, the material would perhaps need to be pre-selected with findings in mind, much like the detained carcasses during the PM inspections. However, this would be difficult to achieve in a real-world setting, again due to the low prevalence. Another possibility is to produce fictive findings which the veterinarians should look for, *e.g.* painting on blood to indicate an injury or the like. However, this then becomes an apples-and-oranges comparison which does not say anything conclusively about the real important findings, only that some lesion could be detected or not.

Even during “normal” AM inspection, a number of assumptions are made. For example, I would argue that most veterinarians in Sweden have not seen live presentations of most epizootic diseases, but nevertheless AM inspection takes place under the assumption that they would capture such diseases if present. Further, the same problem as above, with findings not manifesting themselves during the time of inspection, is relevant here. Because of this, I would argue that AM inspection is far from perfect as it is. Based on the results from the PM part of the study, where agreement could be argued to be very high in the case of clear findings, the same should hold true for AM; if a severe problem were present it would likely be visible on video. More severe animal welfare issues, such as major injuries or malnutrition, could be considered to constitute “clear findings”. The same could be said of severe infections, *e.g.* epizootic diseases such as swine fever, or if an animal was agonal for other reasons.

It could also be argued that, since the assistant is probably a person who works in the pens and has at least some experience with live animals, they would notice more severe cases of disease or injury and inform the veterinarian of them, so that a more thorough inspection could be performed. The assistant may also have seen the animals at unloading, at which point individual animals are more easily discerned and, more importantly, watched in movement, which would reveal any lameness or other signs of weakness.

### 6.2.2 *Post mortem* inspections

*Agreement varies with type of finding*

Agreement seemed to differ very much from one PM finding to another, seemingly in the same way regardless of which pair was evaluated. On the whole, findings ‘systemic infectious disease’; ‘kidney lesion’; ‘swine enzootic pneumonia’; ‘other pneumonia’; ‘pleuritis and/or endocarditis’; ‘no findings’; ‘perceived false arrest’ and ‘totally condemned’ seem to correspond to these dips in agreement. These findings can all be regarded as falling into one of two categories: Either the finding can have very small or vague expression, such as renal abscesses which can be almost point-like, or the finding is of a very subjective nature, such as when to totally condemn a carcass. ‘Kidney lesion’ also represents one of the “non-standard” codes that was introduced in this thesis.

It is worth remembering that OVA and OVB were both kept informed and involved in the design of the data collection, and would therefore both be very familiar with the new codes and conditions introduced. The group of OVs compared in study III were not and, while instructions were given, it is not unreasonable that the poorest agreement was seen within that group.

‘No findings’ and ‘perceived false arrest’ are also strongly connected. In the ideal case, all carcasses marked as falsely arrested would be completely without findings, *i.e*. also marked with ‘no findings’. Since it was not possible to confirm that all carcasses falsely detained by the OA were truly without lesions, the possibility exists that some minor lesions slipped through, which the OA missed and an OV picked up on. That would explain a discrepancy between the prevalence of the two codes. An almost axiomatic assumption would be that OAs are more likely to miss smaller, less distinct, lesions, rather than large lesions, and thus one of the OVs could also have missed them, which could explain why ‘no findings’ appeared to score low prevalence, especially within the larger group of OVs.

### *Equality of methods*

While the results generally suggested high agreement between the on-site and remote inspection methods, there were some problems with the setup of the experiments. The inspections in study II were carried out by two different OVs. It would be preferable for a single person to use both methods to perform a number of inspections, after which a comparison between the methods could be performed. In order to use both methods on the same material, however, the material would need to be inspected with a sufficient time gap so that the user could not remember any potential findings between switching methods. This would of course be unfeasible when examining organic material, especially in a production setting.

While measures were taken to attempt equalisation of the two raters’ assessments, it would be wrong to assume the two to be perfectly synchronised, as confirmed by the pilot study. Because of this, any poor agreement between on-site and remote inspections could be due either to the methods or to differences in assessments between the OVs. Both inter-method and inter-rater agreements work in tandem to give the end result and if total agreement is low, it is unfortunately impossible to know which is the cause. However, in situations where total agreement is high, it cannot be so unless both the methods and the OVs achieve high agreement. The results from study II alone cannot be used as conclusive proof of whether poor agreement is due to the method not conveying enough information, or to differences between the assessors.

In study III, if the remote method really did not convey enough information, a high level of agreement between the raters in the group could be expected, as none of them should have found anything. This was not the case; rather, the agreement was generally worse than found for OVA and OVB in study II. This suggests that some raters observed PM findings and some did not. Since the OVs in the group were informed that carcasses without findings could occur, that should have minimised any random guesses, since there was actually the possibility of there being nothing to find.

In study IV, when the same rater actually rates the same material using both methods, the expected outcome would be perfect agreement if the methods are completely interchangeable. This was not the case either, but the PABAK score was less than 0.8 (weaker agreement) only in one case for rater OVA (‘o findings’), and in two additional cases for rater OVB (‘kidney lesion’ and ‘total condemnation’). Using the interpretation scale of Landis and Koch (1970), this means that for intra-person agreement in both on-site and remote inspection, almost every finding scored “Almost perfect agreement”. This could be interpreted as a difference between video and on-site inspections, but there are still confounding factors. For example, the OVs inspected pre-recorded videos produced by each other, which means that slight differences in inspection methodology could have affected the results. In fact, there was substantial difference between the average inspection times by OVA and OVB, with OVB’s inspections being on average almost two minutes longer. Perhaps OVB was more thorough and thoughtful in their inspections, which would give OVA very thorough videos to inspect and similarly penalise OVB since they would be accustomed to that level of thoroughness, which perhaps OVA’s videos lacked. Löw *et al.* (2015) have previously noted that longer, more thorough video inspections lead to higher accuracy in human video diagnostics.

There is also the possibility of some element of chance affecting the inspections, where the same presentation of findings would yield different outcomes. This is not unexpected, since there is always a subjective nature to meat inspection and the human factor can of course come into play. Stärk *et al.* (2014) reasoned that differences in experience and knowledge, and in opinion, motivation and dedication, could explain variations in agreement between meat inspection personnel. Motivation and dedication can also vary within an individual, which could cause variations in agreement.

A way to evaluate this further would be to perform a test-retest analysis on both OVA and OVB, where they inspected the same videos again. This was not been performed as a part of the work in this thesis.

The most likely conclusion is that the methods perform similarly, or at least display a high amount of inter-method agreement. This is perhaps not 100% conclusive, since many findings displayed relatively low prevalence and, even if a prevalence-adjusted measurement is used, it may not really say much if two raters achieve high agreement when the prevalence of a finding is, say, in the range of 1-5%. Most of the agreement would stem from negative cases.

### *Potential consequences for consumer safety*

Hill *et al.* (2003) compiled a list of findings at slaughter based on the risk level for consumers and considered only two diseases to be primarily transmitted to humans through consumption of pork: roundworms and acute pericarditis. Most observable and recorded findings thus relate instead to meat quality (EFSA, 2011; Laukkanen-Ninios *et al.*, 2020).

Based on those claims and the results from studies II-IV, performing PM inspections remotely should have very little bearing on consumer safety. Considering the results from study IV in particular, the method scored “nearly perfect agreement” in almost all cases. Since study IV produced these high agreement figures when the same person used both methods, a reasonable assumption would be that there is very little difference between the two methods. If this reasoning holds true, this would also mean that the group-agreement figures in study III would be transferable, at least with a margin of error, to inspections performed on-site. Overall, this would indicate rather poor agreement within that random group of OVs for certain findings, especially whether or not to totally condemn a carcass. Very little work has been done to compare agreement between Swedish OVs. Arzoomand *et al.* (2019) previously found similarly poor kappa-based agreement between OVs about whether a carcass should be totally condemned or not. In the US, Davies *et al.* (1996) found high agreement among veterinarians as regards presence of enzootic pneumonia and white spots on livers, but comparatively poor agreement in detecting pleuritis in the lungs. They also noted that agreement was higher for veterinarians who had undergone repeated training.

Based on the results in this thesis, I would argue that since agreement between on-site and remote PM inspection in both studies II and IV was higher than the agreement within a larger group of OVs at the Swedish Food Agency in study III, the same OV switching from on-site to remote inspection would result in more equal inspections than a switch to another OV, something which is routinely done today without consideration of conformity and validity.

*Training*

There is likely an element of training in accurate use of the remote inspection method. Initially, both OVs reported a lack of depth perception and slight colour differences as factors making the method feel alien. Over time, the OVs became more accustomed to the method and felt more secure in their assessments. In study II both OVs were completely new to the method and had to learn and adjust ‘on the fly’. If a shift to remote meat inspection is to be implemented, it would be prudent to provide OVs with advanced training in using the method. One way of achieving this would be to have another OV play the role of on-site camera technician, performing inspections and presenting any findings, while the learning OV watches. This would allow the learner to have findings presented without the risk of missing them (in theory), and would enable them to properly adjust to how findings appear on the monitor. Woodworth & Thorndike (1901) suggested that optimal transfer of training occurs when the training is performed in the same settings and context as the later work.

## 6.3 Calculated economic viability

Since remote meat inspection takes longer to perform, on average about three times longer for in-depth veterinary inspection, it follows that it is not always cost-effective. The increased inspection time per animal must be outweighed by the savings on travel. Unsurprisingly, economic viability favours a large distance to the facility and a low number of inspected animals.

Note that the values obtained in study II, which evaluated remote in-depth veterinary inspection in pigs, are almost certain to differ at least somewhat for other species and if the inspection is in-depth or at the regular OA level.

The time used for inspection is also an average value from a sample with a comparatively high number of findings. If inspection is performed by OAs, there will probably be more carcasses without findings and the inspection times will likely decrease, at least for on-site inspections, which could lead to a larger difference between the methods.

There are also factors which were not included in the model, such as the time for changing clothes at the facility or setting up and starting the video call, office rental costs, costs of insurance *etc*. Some of these costs would probably cancel out the difference between remote and on-site inspection, and other coats are almost impossible to estimate and were therefore disregarded.

While the model for economic viability used estimated values from a specialist use-case and was associated with a degree of uncertainty in terms of other costs, the relationship between number of inspected animals and distance should nonetheless be linear, with the highest economic gains when remotely inspecting very few objects at a facility very far away (Figure 22).

When comparing two cases of slaughtered animals per day, 8 cattle *vs*. 80 sheep, it becomes apparent that the minimum distance at which a small-scale slaughterplant can be situated for remote inspections to be viable quickly increases when increasing the number of animals, from 12.5 km to 125 km. While 80 heads of cattle daily would be unreasonable at a small-scale facility, 80 sheep is well within the scope of such a company. I would argue that very few slaughterhouses are situated at distances on the scale of 125 km from the Swedish Food Agency’s base of operations.

The minimum distance would also be increased by a factor of two if the slaughterhouse’s operations allow for AM and PM inspections to be performed simultaneously by the visiting personnel, since one return trip would be removed which puts remote inspections at a further disadvantage time-wise. In the case of 80 slaughtered sheep this means a minimum distance for economic viability of 250 km, a distance which seems even more unlikely for any control personnel to travel routinely.

The conclusions drawn from this is that even though the numbers presented in the cost function are associated with a large degree of uncertainty, remote PM inspections are likely not viable for every small-scale slaughterhouse, but rather only for the really small ones processing animals at perhaps the scale of ten to fifteen per day or less. Since smaller species of animals, *e.g.* sheep, can be slaughtered more quickly, perhaps it is reasonable to assume the method would see the most usage when inspecting cattle.

## 6.4 Methodological considerations

### 6.4.1 Strengths and weaknesses of using kappa

If two raters are to evaluate a number of objects for the binary presence of a certain finding, in this thesis a given lesion on a pig carcass, the agreement between them must be scored. At first glance the solution would appear simple; check how many of the observations in which raters both say lesion X is present and divide that by the total number of inspected carcasses. This measure is often referred to as percentage agreement. While it sounds like a sufficient metric of agreement, there is at least one obvious flaw – the raters may not know for sure and make guesses. Jacob Cohen identified this possibility and developed a chance-corrected measure of agreement, which is intended to correct for the possibility of agreement stemming from guesses. This metric, known as Cohen's kappa (Cohen, 1960), assumes values in the range -1 to 1, where 1 indicates perfect agreement and -1 indicates perfect disagreement.

Since Cohen's kappa can assume any value in this range, a five-step scale has been suggested to simplify interpretation. It is defined as: 0.01-0.20 representing "None to slight agreement", 0.21-0.40 "Fair agreement", 0.41-0.60 "Moderate agreement", 0.61-0.80 "Substantial agreement" and 0.81-1.00 "Almost perfect agreement" (Landis & Koch, 1977). This scale can obviously lead to problems and Cohen's kappa has been accused of being difficult to interpret (Di Eugenio & Glass, 2004; Sim & Wright, 2005), because the suggested grading is somewhat 'arbitrary and rough' (McHugh, 2012). Differences in agreement as large as 0.2 can yield the same result, and a difference of 0.01 can change the level from *e.g.* moderate to substantial agreement. Further, identical levels of percentage agreement can yield very differing kappa values, and conversely very different levels of percentage agreement can produce the same kappa value (Byrt *et al.*, 1993).

Cohen's kappa has been shown to be susceptible to the prevalence of whatever finding is being recorded, with low prevalences tending to produce lower kappa values even though observed percentage agreement is high (Thompson & Walter, 1988; Cicchetti & Feinstein, 1990; Feinstein &

Cicchetti, 1990; Byrt *et al.*, 1993; Di Eugenio & Glass, 2004; Nelson & Edwards, 2008; Hallgren, 2012). Logically, if there are few positive observations, any positive chance agreement would have higher impact. Byrt *et al.* (1993) introduced what they called prevalence- and bias-adjusted kappa, PABAK, to deal with this effect, by correcting Cohen's kappa according to an index value calculated from the observed prevalence of positive ratings.

But what does it really mean to be chance-corrected? Aside from the argument on whether chance agreement is even necessary to correct for (Uebersax, 1987), there have been other criticisms of Cohen's kappa. Feinstein & Cicchetti (1990) argued that one of its flaws is to assume each rater has a fixed prior probability of making positive or negative ratings, which would be an unwise assumption in a population with unknown distribution of the assessed quality. Zhao *et al.* (2013) extended this by stating that Cohen's kappa always assumes total randomness, *i.e.* the raters always guess at the toss of a coin. This is very likely not the case if educated raters assess something within their field of expertise; they would likely make an educated guess as to whether disease X was present or not. This assumed coin-toss guessing would deflate the agreement, leading Zhao *et al.* (2013) to conclude that what they call "true agreement" is most likely situated between Cohen's kappa and percentage agreement. In paper II, it was noted that PABAK must take on values in this span, and as such might be a suitable indicator of agreement. However, no single measure may be sufficient to convey an accurate picture of inter-rater agreement, and thus the wisest option is perhaps to calculate all three (Kappa, PABAK and percentage agreement), and use them in conjunction to determine how well two raters compare.

### 6.4.2 Almqvist's PABAK

While Cohen's kappa works for cases with two raters, situations with more than two raters are also important. Chance-corrected measures of agreement for more than two raters have thus been developed, *e.g.* Fleiss' kappa (Fliess, 1970) and Light's kappa (Light, 1970), among others. Fliess' kappa is actually a generalisation of another measure of agreement, Scott's *pi* (Scott, 1954), and Light's kappa is a more simple construct of the average value of all pair-wise Cohen's kappa values within a group. These extensions to multiple raters are also vulnerable to the same prevalence-related issues described above (Mitani *et al.*, 2017).

After scouring the journals, no mention of a prevalence-adjusted kappa-based measure of inter-rater agreement for more than two raters could be found. A new measure was thus developed in Paper III based on the principles of Light's kappa, but using Byrt *et al.*'s PABAK as a base.

This should theoretically give an estimate of the prevalence- and bias-adjusted inter-rater agreement within a group of raters. Although the relevance of Light's kappa has been debated (Gwet, 2004), when evaluating inter-rater agreement within a group of official veterinarians in Paper III, Light's kappa very closely resembled the more established Fleiss' kappa and performed almost identically, especially if the interpretation scale suggested by Landis and Koch (1971) was used. When comparing this new Almqvist's PABAK to both Fleiss' kappa and the average percentage agreement within the group, it was found to perform in much the same way that PABAK does when compared with Cohen's kappa and percentage agreement, *i.e.* somewhere between the two. Assuming that the principle behind Light's kappa is sound (based on the observed minute differences from Fliess' kappa) and accepting the reasoning that "true agreement" is somewhere between Cohen's kappa and percentage agreement (Zhao *et al.*, 2013) and is thus well represented by PABAK (Paper II), Almqvist's PABAK would indeed be a relevant measure of prevalence-adjusted inter-rater agreement within a larger group of raters. More research into this topic is needed in order to substantiate this claim.

### 6.4.3 Sampling and external validity of the results

The research in this thesis was conducted exclusively during in-depth veterinary inspections at a large-scale slaughter plant, while the main use of the studied remote video-based method is, rather, OA inspections at small-scale facilities. Moreover, the sample that we used PM was artificially constructed from purely arrested carcasses, and not representative of the population of carcasses at ordinary slaughter. The sample consisted of arrested carcasses together with healthy ones in a way that would likely never appear in a real slaughter setting. Information about the prevalence of various findings at slaughter in Sweden was not readily available. Still, based on the number of arrests per day and the total number of slaughtered animals, the prevalence of most findings at ordinary slaughter is likely on the order of 100 times less compared to the sample that we used. Had the sample instead been purely from arrested carcasses, the prevalence would be around twice as high. However, not all findings are cause for arrest at slaughter. Some codes, such as ‘white spots’ (code 84), could be expected to have a higher prevalence at ordinary slaughter than what we found. Findings that are relatively independent of other codes, again exemplified by ‘white spots’, may have a similar prevalence at OA inspection of all carcasses as at in-depth veterinary inspection of arrested carcasses.

As stated previously, Cohen’s kappa is sensitive to differences in prevalence and would likely be higher if the sample had been from a population of purely arrested pigs. Exactly how high is difficult to estimate, because kappa increases non-linearly with increasing prevalence (Byrt et al., 1993). If the sample had instead been drawn randomly from the entire population, i.e. carcasses at OA inspection, the kappa values would have been much lower, due to the large difference in prevalence. Since PABAK is relatively unaffected by the prevalence of findings, those values should have remained the same regardless of which sample was used. Still, if the prevalence was very low (such as at ordinary OA inspection) it would be difficult to draw any meaningful conclusions from the agreement values. This is a problem for the low-prevalence findings even in the sample used here. Because of this, the calculated agreements should be interpreted cautiously, especially for the findings with very low prevalence.

A sample that was representative of ordinary slaughter would perhaps have been preferable, but was deemed less suitable under the circumstances. The aim was not only to assess the agreement for a given finding, but also for "no findings", which could not have been achieved if only properly arrested carcasses had been used. A sample from all OA-inspected carcasses would have had to be extremely large and therefore unfeasible.

The sample size of 400 carcasses PM and 400 groups of animals AM was calculated based on a preliminary study layout with comparisons of proportions between methods or raters, where the assumed average prevalence was 50% and a difference of 10 percentage points or higher was detectable with a power of 80% and a significance level of 5%. These assumptions yielded a minimum sample size of 385, which was rounded up to 400.

Given that the analysis was later changed from comparisons of proportions to kappa-based statistics this sample size would likely be different had those methods been taken into account instead, but 400 is nonetheless a large number of observations which should still yield enough statistical power.

In hindsight, given the time allotted by external factors, e.g. using personnel from the Swedish Food Agency and intruding on a slaughterhouse's operations, to conduct the data collection, this figure was about as large as the sample could be.

It might be argued that the applied sampling strategy made it difficult to draw conclusions about the functionality of the remote method in real slaughter, and in other species than pigs. However, there is no reason to believe that the results in this thesis are not applicable to ordinary small-scale slaughter and transferable to other species such as cattle, sheep or reindeer. A lung lesion in a pig probably looks similar to a lung lesion in another species and the almost axiomatic assumption that a clear finding will always be discovered can still be applied. However, we have not been able to quantify the remote method's reliability for findings that are unique to a particular species and thus do not occur in pigs, *e.g.* liver flukes in cattle.

Pigs rely exclusively on ocular inspection, while other species require routine incisions and/or palpation, but this should pose little problem if the augmented reality overlay is used. The remote inspection would obviously take a longer time to complete because of this; however, since the assistant in this thesis required fewer instructions over time, it is also reasonable to assume that personnel at slaughter plants would become increasingly proficient, especially for routine work, which would decrease this time difference.

The results should also be applicable regardless of facility, as long as network conditions are sufficient. The room in which the carcass is inspected should not matter, assuming it is possible to carry out an on-site inspection at all. The main challenge would be to ensure that every small-scale facility where remote meat inspection is implemented has an internet connection of sufficient standard, but since most companies rely on internet connectivity for their own practices this should not pose a significant problem.

## 6.5 Implications for future research

This thesis has several implications for future research. Four potential topics for new research projects, building on key findings in this thesis or other observations, are presented below.

### 6.5.1 The continued validation project

A future research project should continue exploration of the solution and method presented in this thesis. The results are likely to be transferrable to other settings and species, but this should be experimentally verified, preferably avoiding the confounding factor of using more than one rater. Further, the methodology still needs to be evaluated during AM inspections

### 6.5.2 The advanced technologies project

A future research project should investigate the use and/or adaptation of more advanced technologies, such as automatic image analysis using artificial intelligence and/or more complex uses of augmented reality, in veterinary meat inspection.

### 6.5.3 The economics project

A future research project should assess the economic implications of the methodologies and technologies investigated and similar solutions, focusing on dynamics on the supply side, demand side, or both. It should determine how much can be gained by the shift to a remote meat inspection method, and when should such methodologies be implemented.

### 6.5.4 The management project

A future research project should examine the organisational implications (*e.g.* effects on productivity and employee job satisfaction) of implementing remote veterinary meat inspection using the technologies discussed in this thesis, or other technologies.

# 7. Conclusions

- Remote veterinary *post mortem* inspections can be carried out using a waterproof smartphone, together with an application for two-way video communication. Hardware that satisfies both hygiene and ease-of-use requirements is commercially available.
- Remote inspections are highly reliant on a stable internet connection offering a bandwidth of at least 3 Mbit/s. While 4G networks can offer this bandwidth, there are indications that it may fluctuate too much to provide sufficient image quality for remote inspections.
- Inter-method agreement between on-site and remote veterinary *post mortem* inspections appears to be very good, especially when the same rater uses both methods. Remote veterinary *ante mortem* inspections could not be evaluated using this type of study design.
- Agreement between remote and on-site inspections for each *post mortem* finding is higher than the agreement for the same findings within a group of official veterinarians performing inspections on pre-recorded videos. This suggests that observed differences between the methods are due to different raters, and that a shift to the new methodology would have less impact than replacing one official veterinarian with another.
- Remote veterinary inspection appears to be most economically viable when inspecting few animals or carcasses at a slaughter facility far away from the veterinary inspection offices.

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# Popular science summary

## Who you gonna call? Examining the possibilities of remote meat inspection

The Swedish slaughter industry is undergoing major changes back towards smaller operations, with an increasing number of smaller companies entering the market. Today there are over 90 small-scale slaughterhouses operating in Sweden, and many of these are situated in distant countryside. Consumer demand for locally produced meat is increasing as there are many animal welfare gains in local production, such as shorter transport of animals. The Swedish government has also established the goal of increasing Sweden's self-sufficiency when it comes to foodstuffs.

Every animal destined for slaughter in Sweden must be inspected by the Swedish Food Agency. The live animals are inspected before slaughter and their carcasses are inspected after slaughter. These inspections are performed in order to ensure that the animals are healthy and the meat produced is safe for consumers. The inspections performed at small-scale slaughterhouses are often performed entirely by veterinarians employed by the Swedish Food Agency. Since many small-scale slaughterhouses are located deep in the countryside, these veterinarians often have to travel long distances to perform the inspections, with substantial time and cost expenditure.

Today it is possible to see a doctor or other caregiver using a smartphone app. If the same principle could be applied to inspections at slaughter, travel to perform statutory on-site inspections could be reduced, saving both money and the environment. An assistant already present at the slaughterhouse could, via a video link, display the animals and carcasses, and personnel from the Swedish Food Agency could perform the inspections from an office located elsewhere.

Inspections, mainly of carcasses, require a certain degree of manual work. If a blemish is found on a carcass, it may require a more in-depth examination through touching and/or cutting into it. Specialist competence is required to perform the inspections and a high level of knowledge is important in order to make accurate examinations. If the inspections are performed remotely with someone assisting on-site at the slaughterhouse, it is imperative that the person on-site can be instructed in how to perform examinations correctly and at precisely the right place on the carcass.

Augmented reality, a technology that blends a computer-generated image with an image of the real world, has many uses. The best-known example of its use is probably the mobile game Pokémon Go, where fictional little monsters, Pokémon, can be captured in the real world. Besides entertainment, the technology has proven to be useful in quickly conveying complex instructions, since a picture is often worth a thousand words. Augmented reality has the potential for greatly simplifying remote inspections at slaughter if the person assisting on-site can be shown in real time how to perform an examination or what finding to focus on, instead of being told verbally.

This thesis evaluated how a technical setup for conducting remote inspections at slaughter could be achieved and how it functioned during practical application, and assessed remote inspections at slaughter in terms of how they actually performed compared with inspections performed on-site. The evaluations were based on data from 400 pigs in groups and 400 pig carcasses, which were inspected using conventional on-site inspection and also using remote video inspection with augmented reality functionality.

In a preliminary study, requirements that need to be fulfilled by a technological setup suitable for use in a slaughter setting were identified. It was found that the setup should be simple, practical and economic to use, and allow for augmented reality. A viable setup was put together and evaluated in practical use. The setup which met the criteria best was a waterproof smartphone running specialised augmented reality software, mounted in a holder placed on the back of the on-site assistant's hand. This placement allowed the assistant to use both hands for gripping and cutting into the carcass, while the smartphone camera relayed video of the carcasses while the display remained visible in order to receive augmented reality instructions.

In a follow-up study, two veterinarians inspected the same animals and carcasses using one method each, one on-site at the slaughterhouse and the other at an office with an assistant on-site relaying video and performing manual examinations with instructions from the veterinarian. The assistant had not worked with inspections of animals or meat previously. The veterinarians switched places half-way through the study, so each one inspected 200 groups of animals and 200 carcasses using either method. The veterinarians performed their usual inspections and recorded findings present from among a list of nine types of findings for live animals, using 26 established codes for *post mortem* findings when inspecting carcasses. A comparison of the results was then made and the level of agreement between the two veterinarians was calculated using common statistical measures of agreement (how similar their assessments were). Agreement was shown to be relatively high, meaning that the two veterinarians found roughly the same things when performing the inspections. Some findings showed lower agreement, however, particularly very small blemishes or lesions requiring subjective interpretation by the veterinarian. Because two different veterinarians performed the inspections, it was not possible to determine whether this lower agreement for certain *post mortem* findings stemmed from the inspection methods performing unequally, or from differences in how the two veterinarians assessed the material. The method could not be evaluated on live animals, since the current good state of pig health in Sweden meant that there were simply not enough defects for the veterinarians to find when performing their *ante mortem* inspections.

Next, nine veterinarians employed by the Swedish Food Agency were asked to review recordings of the remote inspections conducted by the two veterinarians in the previous study. They performed inspections on the material in the same way and agreement between them was calculated in a similar fashion. A similar trend was found, with relatively high agreement for certain *post mortem* findings and lower agreement for others. Again, the findings that showed low agreement were those that required subjective assessment. Overall, the agreement was lower than that observed between the two veterinarians in the previous study.

In a final study, the two participating veterinarians from previous method comparison work inspected 200 of the 400 recorded remote inspections each. The 200 inspected videos were of the same carcasses that each veterinarian had inspected on-site at the slaughterhouse in the method comparison study.

Each veterinarian thus inspected 200 carcasses both on-site and via video and again agreement for findings was calculated between the methods. When the same person performed inspections using both methods, agreement was near perfect for all findings.

Apart from the four aforementioned studies, a simpler economic model for when remote inspections are viable has been drawn up, based on the distance to the slaughterhouse contra the number of inspected carcasses.

In summary it appears viable to perform remote inspections at slaughter using a smartphone running specialist software for video calls combined with augmented reality functionality. Such remote inspections appear to perform equally well to inspections conducted on-site, especially when the same person performs both. Observed differences between the two methods were substantially smaller than the differences observed within a group of veterinarians, which means that a shift to remote inspections at slaughter would likely have less impact than changing from one veterinarian to another. In financial terms, video inspection is likely to be economically viable when small numbers of animals are inspected at distant slaughter facilities.

# Populärvetenskaplig sammanfattning

## Who you gonna call? En undersökning av möjligheterna kring distansbaserad köttbesiktning

Slakteribranchen i Sverige genomgår just nu stora förändringar mot det mindre, med allt fler småskaliga aktörer som ger sig in på marknaden. Idag finns uppåt 90 småskaliga slakterier i drift i Sverige, och många av dessa ligger på landsbygden. Konsumenterna efterfrågar i allt större utsträckning närproducerat kött, och det finns många vinster i djurvälfärd att vinna på lokalproduktion, som till exempel kortare transporter av djur. Dessutom har regeringen uttryckt önskemål om att öka Sveriges grad av självförsörjning när det kommer till livsmedel.

Alla djur som går till slakt i Sverige måste besiktigas av Livsmedelsverket. Dels besiktigas varje djur levande innan slakt, och sedan besiktigas varje slaktkropp ytterligare en gång. Detta för att säkerställa att djuren är friska, och att det kött som konsumenterna köper inte gör någon sjuk. Besiktningarna vid småskaliga anläggningar utförs ofta av veterinärer anställda av Livsmedelsverket. Eftersom många småskaliga slakterier ligger ute på landsbygden får dessa ofta resa långa sträckor för att genomföra besiktningarna, något som kostar både tid och pengar.

Idag är det fullt möjligt att träffa en läkare eller annan vårdgivare via en app i sin telefon. Om samma princip kunde användas för besiktningar i samband med slakt skulle de resor som idag är nödvändiga kunna minskas avsevärt, vilket skulle spara både pengar och miljö. Någon som redan är på plats på slakteriet skulle då kunna visa upp djur och slaktkroppar via videolänk, och Livsmedelsverkets personal kan utföra besiktningen från ett kontor någon helt annanstans.

Besiktningarna, framför allt av slaktkroppar, kräver dock en del manuellt arbete. Hittar man något avvikande kan detta behöva undersökas närmre genom att man klämmer, känner eller skär i det. Det krävs speciell utbildning för att få genomföra dessa besiktningar, och det är viktigt att man vet vad man gör så att det blir rätt. Om man får hjälp av någon på slakteriet är det otroligt viktigt att den personen kan instrueras att göra precis rätt undersökning, på rätt sak, på rätt sätt.

Augmented reality, en teknologi som blandar en datorgenererad bild med en bild av verkligheten, har idag många användningsområden. Det kanske mest kända exemplet just nu är mobilspelet Pokémon Go, där man kan fånga fiktiva små monster, Pokémon, ute i riktiga världen. Förutom underhållningsvärde har teknologin även visat sig väldigt lämplig för att snabbt förmedla komplexa instruktioner, då en bild ofta säger mer än tusen ord. Augmented reality skulle kunna underlätta enormt vid besiktningar i samband med slakt, om den som utför besiktningen i realtid kan visa för personen på slakteriet hur man utför en undersökning och vilka fynd som kräver närmre inspektion, istället för att behöva berätta med ord.

I denna forskningsavhandling har två saker undersökts. Dels hur en teknisk lösning för att genomföra sådan fjärrbesiktning med hjälp av augmented reality skulle kunna se ut och hur den sedan fungerade under praktisk användning, och hur fjärrbesiktning faktiskt presterar jämfört med den besiktning som sker på plats på slakteriet. Resultaten baseras på en stor datainsamling, där 400 grupper av grisar, och 400 slaktkroppar från samma djurslag har besiktigats med de bägge metoderna, som legat till grund för fyra stycken delstudier.

Initialt utreddes vilka krav som behövde ställas på en teknisk lösning som dels skulle tåla att användas i slakterimiljö, och skulle vara enkel, praktisk och ekonomisk att använda för att genomföra fjärrbaserade slaktbesiktningar med hjälp av augmented reality, och den tekniska lösningen utvärderades genom praktiskt användande. Det visade sig att den lösning som passade bäst var en vattentät smartphone, med en hållare som placerade den över handryggen. Denna placering gjorde att användaren fick bägge händer fria för att greppa och skära i slaktkroppar och organ samtidigt som telefonens kamera kunde användas för att filma materialet, och displayen var synlig vilket gjorde att visuella instruktioner via augmented reality kunde ses.

Vidare läts två veterinärer besiktiga samma djur och slaktkroppar med varsin metod. Den ena på plats på slakteriet, och den andra från ett kontor, men med hjälp av en person på slakteriet som filmade och utförde undersökningar efter instruktioner från veterinären. Denna person hade aldrig tidigare arbetat med djur- eller köttkontroll. Veterinärerna bytte plats halvvägs genom försöket, och besiktigade på så sätt 200 djurgrupper och slaktkroppar med vardera metoden. Veterinärerna gjorde sina besiktningar, registrerade om och vilka fynd de hittade, utifrån en lista på nio fynd för levande djur och 26 tänkbara sådana för slaktkroppar. Efteråt gick det att jämföra om och vad de hittade, och sedan beräkna ett mått på *samstämmighet* mellan dem, alltså hur pass lika deras bedömningar var. Det visade sig att samstämmigheten överlag var hög, det vill säga att veterinärerna hittade ungefär samma saker vid sina besiktningar. Vissa fynd visade lägre samstämmighet, och det var framför allt fynd som kan ta sig små uttryck eller kräver en subjektiv bedömning av veterinären. Eftersom två olika veterinärer utförde besiktningarna var det inte möjligt att säga om skillnaderna i samstämmighet för dessa fynd berodde på om metoderna inte var lika bra på att hitta saker, eller om det var veterinärerna som bedömde saker olika. Tyvärr kunde metoden inte utvärderas för besiktning av levande djur, då det på grund av det goda hälsoläget bland grisar i Sverige helt enkelt inte fanns tillräckligt många fynd för veterinärerna att hitta.

Härnäst läts nio stycken veterinärer vid Livsmedelsverket titta på inspelningar av de fjärrbesiktningar av slaktkroppar som gjorts i studie 2. De gjorde samma typ av besiktning, och samstämmigheten mellan dem beräknades på liknande sätt. Här sågs samma trend, med relativt god samstämmighet för vissa fynd, och sämre för andra. Igen var det mer vaga, subjektiva bedömningar som visade lägst samstämmighet. Överlag var dock samstämmigheten inom gruppen lägre än vad som sågs mellan de två metoderna i studie 2.

Slutligen fick de två veterinärerna från den första metodjämförelsen besiktiga 200 av de 400 inspelade fjärrbesiktningarna av slaktkroppar var. De 200 som besiktigades var samma 200 slaktkroppar som den veterinären bedömt på plats på slakteriet tidigare. De två veterinärerna hade på så sätt besiktigat 200 slaktkroppar var både på plats på slakteriet och via video. Återigen beräknades samstämmigheten för fynd, och det visade sig att när samma veterinär besiktigar samma slaktkroppar med bägge metoder uppnås en nästan perfekt samstämmighet för samtliga fynd.

Utöver dessa studier har en enklare ekonomisk modell för när fjärrbesiktning är lönsamt ställts upp, baserad på avstånd till slakteriet kontra antalet besiktigade slaktkroppar.

Slutsatserna från denna avhandling är att det verkar fullt möjligt att utföra fjärrbaserad besiktning vid slakt med hjälp av en smartphone tillsammans med specialiserad mjukvara för videosamtal med stöd för augmented reality. Vidare verkar fjärrbaserad besiktning vid slakt prestera likvärdigt med besiktning på plats, framför allt när man låter samma person utföra besiktningarna. De skillnader som ses mellan de två metoderna är betydligt mindre än de som sågs inom en större grupp veterinärer, vilket gör att en övergång till fjärrbesiktning sannolikt skulle leda till mindre skillnader i besiktningen än om man låter en annan veterinär utföra den. Ur ett ekonomiskt perspektiv verkar fjärrbesiktning löna sig allra mest när ett fatal slaktkroppar besiktigas på ett slakteri långt bort.

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Official control at remote small-scale slaughterhouses entail substantial costs. These costs could be reduced by performing meat inspection remotely. This thesis aims to create and test a technological setup using augmented reality for use in remote inspections at slaughter, and evaluate how these perform compared to conventional on-site inspections. It appears possible to conduct remote meat inspections using a contemporary smartphone, and such inspections agree in most cases nearly perfectly with on-site inspections.

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