The PhD projects of PigIT

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Chapter 1

General introduction to the four PhD projects of PigIT

1.1 Objective and hypotheses

The PhD projects are part of the larger research project "PigIT - Improving welfare and productivity in growing pigs using advanced ICT methods" financed by the Danish Council for Strategic Research and running from 2012 to 2016. In the following the acronym "PigIT" will refer to the main project.

The scientific objectives of PigIT are to develop and improve methods for

1. Model based production and welfare monitoring by,
   (a) Optimizing the use of automatic measurements based on sensor technology.
   (b) Improving links between data from different animals and different parts of the herd.
   (c) Enhancing the early prediction and identification of reduced welfare and productivity.
2. Model based decision support by,
   (a) Improving integration of data in the decision process by i) learning parameters from data and ii) implementing industrial methods for process design, control, and development.
   (b) Ensuring optimal decisions by integrating indicators of animal welfare and productivity.
   (c) Developing optimization algorithms, which can handle multiple decision criteria and multiple levels.

It is the overall hypothesis of PigIT that a systematic placement of cheap sensors in the production pens combined with methodological developments to integrate the information from these sensors will improve the production process and thus add significant value to investment in the sensor technology. The potential benefit will be seen in productivity as well as in the welfare of the animals in the systems.

A total of 4 PhD projects are defined within PigIT:

PhD 1. Automatic learning and pattern recognition using sensor data.

PhD 2. Methods for prioritization of alarms and intervention.

PhD 3. Optimization methods in a stochastic production environment.

PhD 4. Evolutionary operations as a tool for improving welfare and productivity.

1.2 Background, state-of-the-art and relevance

In the last ten years, noticeable progress in terms of productivity has been reported for sow herds. This has resulted in increased potential for the value chain. However, the part of the value chain coming from growing pigs is currently not fully exploited. This is due to an unsatisfactory level of both welfare and productivity of growing pigs, and to the increasing export of live piglets observed in recent years.

The major welfare problems affecting the productivity of growing and finishing pigs are intestinal (i.e. diarrhea, affecting mostly weaners) and respiratory (affecting mostly finishers) diseases. Other major welfare issues are tail biting and undesired excretory behavior with sudden appearance of filthy floors. The causes of both tail biting and undesired excretory behavior are currently unclear, which makes it difficult to take action to tackle and prevent these welfare issues. Tail docking, which is a painful intervention to prevent tail biting, is only allowed in herds with severe tail biting problems. However, tail biting is currently so common, that tail docking is almost routine practice. Indeed, a better understanding of the causes of tail biting is necessary to avoid both its occurrence and also the practice of tail docking.

Simple sensors are already installed on many pig farms (e.g. temperature, water and feed). Typically, the numbers and positions of the sensors are not directly related to the position and design of the production pens, and it is not possible to e.g. monitor the production in each pen consistently. However, addition of a few sensors plus a systematic approach to the positioning of the sensor promise to add new dimension to the use of the information from the sensors, both with respect to how different parts of production systems function, which types of problems that may be detected, and how the information may be used for a dynamic fine tuning of the production process.

Until now, computer based production monitoring in growing pigs has mainly focused on growth, consumption of water and feed, and mortality. However, in the daily management pig producers rely on additional observations related to animal behavior, e.g. in relation to climate regulations, and early intervention in case of economic and welfare related problems, such as disease and tail biting. These behavioral observations also serve as early indicators in case of feed and growth related problems.

Several research projects described in the literature have tried to develop methods for automatic monitoring in pig production (examples include a group in Helsinki working with detection of farrowing (Oliviero et al., 2008) and a group in Leuven working with detection of respiratory diseases by cough sound analysis (Ferrari et al., 2008)). Also the research groups of PigIT have worked intensively in this field based on techniques such as state space models (Cornou and Lundbye-Christensen, 2010, 2012; Cornou et al., 2011; Nielsen et al., 2011) and Hidden Markov models (Aparna et al., 2011b,a). Data sources have been vision technology (Aparna et al., 2011a; Jørgensen, 2007; Tu et al., 2011), sensors positioned on individual animals (tri-axial accelerometers (Cornou and Lundbye-Christensen, 2010, 2012; Cornou et al., 2011; Marchioro et al., 2011), temperature sensors (Andersen et al., 2008)) and sensors monitoring the environment, i.e. water (Aparna et al., 2011b; Madsen et al., 2005) and climate sensors. Statistical methods based on behavioral theories have been developed, e.g. to describe the choice and lying behavior of the pigs (Damm et al., 2010; Halekoh et al., 2007), and the timing of different motivational states of sows. The previous efforts in the groups have been concentrated on monitoring sows, but the ambition of PigIT is to adapt their methodology to growing pigs and to go a step further and integrate the monitoring methods in active decision support and regulation. This will allow better integration of different information sources and from different parts of the production system.

1.3 Work packages and research themes

The PigIT project is organized with problem oriented work packages and methodologically oriented research themes as illustrated by Figure 1 in the project description. Since the PhD projects are all defined in relation to the methodological themes, but are also committed to the work packages, the interaction and mutual dependence of the research themes and the work packages become very important. An attempt to illustrate how the methodologically oriented PhD projects (corresponding to the four research themes) interact and contribute to the work packages is given in Figure . The vertical arrows illustrate (by their widths) the approximate contribution from each PhD project to the work packages.

For a more thorough description of the themes and, in particular, the work packages reference is made to the project description. As it is also seen from Table 1 of the project description, the work packages do not entirely depend on the PhD students. Post docs and senior scientists also contribute to the work packages.

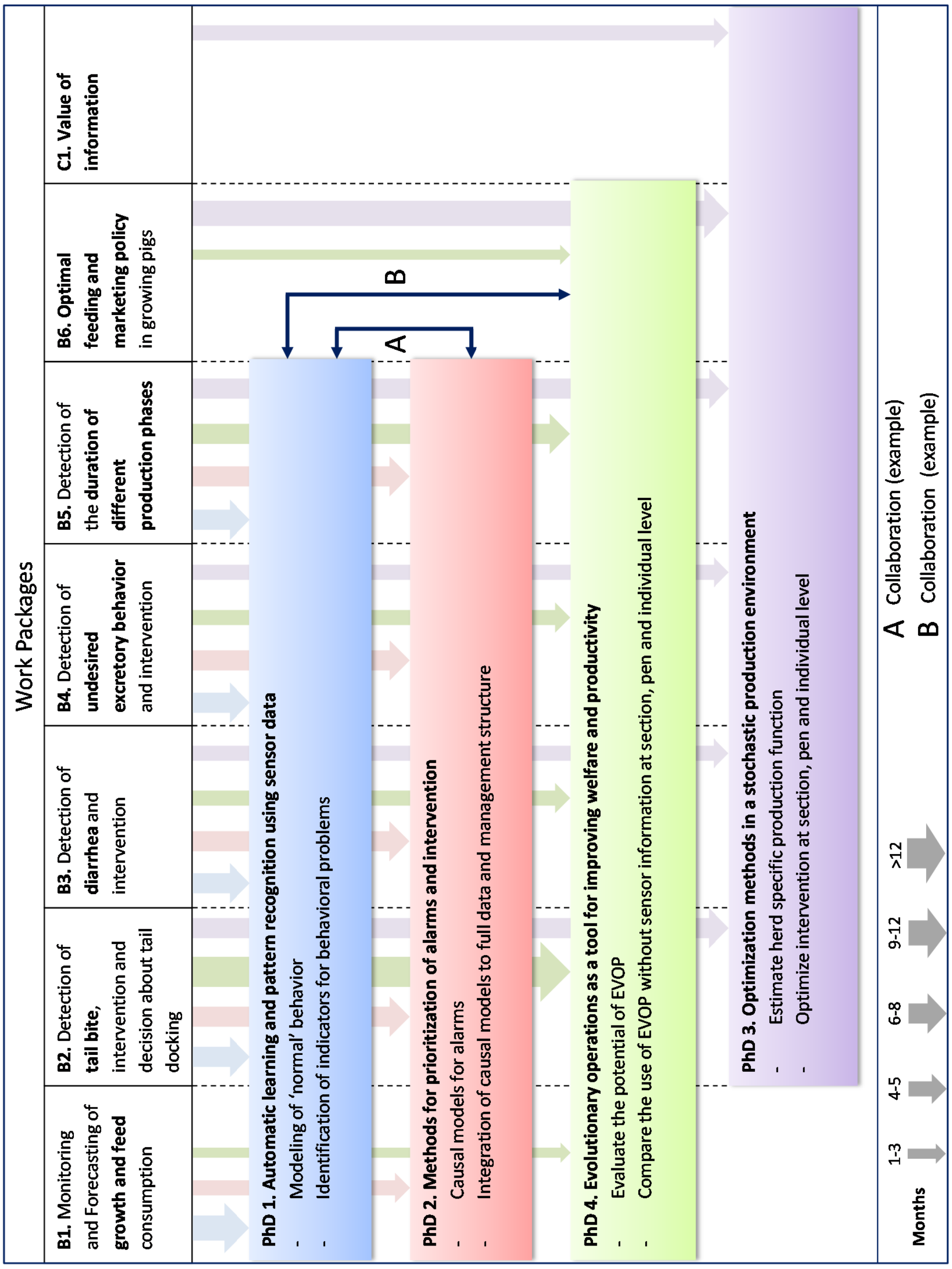

Figure 1.1: Illustration of the interactions and mutual dependencies between the PhD projects and the work packages.

1.4 Practical framework of the PhD projects

The duration of a PhD project at a Danish university is 36 months. Out of those months, approximately 6 months are used for PhD courses leaving around 30 months for the research project.

Two of the four PhD students will be enrolled at University of Copenhagen, Department of Large Animal Sciences. The other two students will be enrolled at Aarhus University (one at Department of Animal Science and one at Department of Economics and Business). Each PhD student will have a main supervisor from the enrolling department, but in addition, an advisory group will be formed for each student. One purpose of the advisory groups is to ensure involvement of several partners around the same PhD project in order to strengthen the mutual integration of the alliance. Another purpose of the advisory groups is to ensure that all necessary scientific disciplines (welfare, herd management etc.) are represented in the cross-disciplinary projects.

The plan is to advertise for the PhD students in the autumn of 2012 so that they can start on January 1st 2013.

Chapter 2

The individual PhD projects

In the following subsections, the four individual projects are described. As concerns the sections "Objectives and hypotheses" and "Background, state-of-the-art and relevance" only those aspects that are specific to the project in question is mentioned.

2.1 PhD 1: Automatic learning and pattern recognition using sensor data

2.1.1 Objectives and hypotheses

The objective of this project involves development of methods for on-line learning of specific properties regarding important production and behavioral traits in growing pigs at animal, pen and batch level. Sensor data will include live weight, feed intake and water intake as well as activity level, measured in different ways (vision, infrared sensors, visits to feeding trough etc). The sensor data will be used for development of online classification and prediction models for monitoring and detection of welfare and production problems. The project will work within the 5 work packages B1-B5.

2.1.2 Background, state-of-the-art and relevance

Model based monitoring of dynamic systems is not a new idea. It emerges from the problems arising in monitoring dynamic and continuous processes such as those at work in a chemical or power plant. Dvorak and Kuipers (1989) describe process monitoring as a continuous real-time task of recognizing anomalies in the behaviour of a dynamic system and identifying the underlying faults. They identify three specific challenges, which definitely also applies to the growing pigs:

1. Diagnosis must be performed while the system operates - an outbreak of diarrhoea or tail biting in a pen of pigs, does not stop the pigs from growing, nor does it stop the next batch of pigs needing the pen in a few weeks' time.

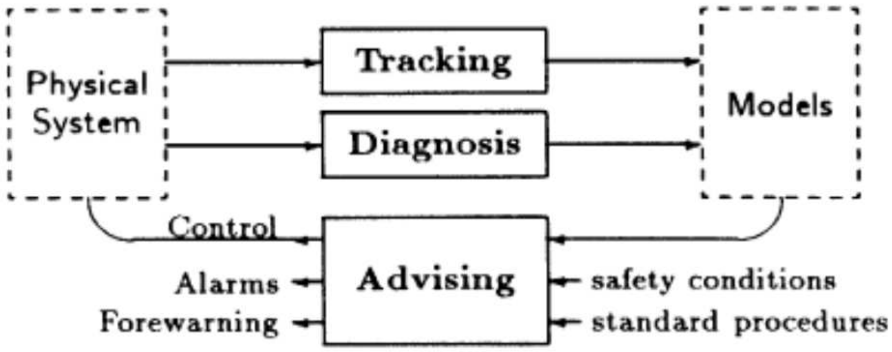

Figure 2.1: The basic idea of a model ba<sed monitoring of a dynamic system.

2. Few system traits are observable - All measurements come from sensors (and additional clinical observations) which are expensive and/or unreliable and/or potentially invasive. Monitoring is based on (typically) a small subset of the system parameters, with limited or expensive possibilities to investigate further parameters.

3. The systems are dynamic - the sole purpose of growing pigs is that they grow, i.e. pigs constantly change, thereby affecting the pen and other production facilities differently.

The basic idea of a model based monitoring of a dynamic system is outlined in Figure 2.1 (c.f. (Dvorak and Kuipers, 1989)). The tracking part is what evolves the model through observations/sensor input from the physical system. The diagnosis component identifies problems or unwanted behaviour and updates the model so that predictions are in accordance with the actual state of the system. The advising component presents the information from the tracking and diagnosis (along with prioritization/advice with respect to the optimal decisions) to the farmer. The present PhD only focuses the tracking and diagnosis, the advising/feedback is addressed in another PhD project.

2.1.3 Research plan and methods

The PhD will use data acquired in other parts of the PigIT project. Specifically, the project will use time series of sensor data, coupled with data defining the true status of the system, i.e. independent data confirming the occurrence of events that are relevant to diagnose.

The primary task of the PhD is to develop the tracking and diagnosis components in a model based monitoring system utilizing information from potentially multiple sensors working at different levels, i.e. section, pen or pig level. An important aspect of this development is believed to be to address how different unwanted events, such as tail biting or diarrhoea, are affecting the sensor observations. Particularly how early unwanted events can be predicted.

To a large extent, the research plan and applied methodologies depends on the skills of the PhD Candidate, but focus will be on methods that can improve the handling of important welfare problems which also have a negative influence on productivity. The ambition is to use on-line data to identify the problems and, particularly, identify behavioral patterns preceding the condition. Machine learning/ pattern recognition algorithms will be adapted for detection of indicators for coming outbreak of the problem.

A preliminary plan is expected to include the following elements:

- Critical review and assessment of existing methods and models; within livestock, but also in other fields. Elements to be consider in the assessment of suitable methodologies are (among others): capabilities of handling missing data/gaps in data; integration of data from multiple sensors; and potential for including exogenous discrete event data, such as clinical observations or logbook entries made by farm personnel.

- Based on the critical review a number of possible methodologies are implemented and tested. It is of particular interest that the implementation allows for easy integration of several undefined sensors, but also that communication between the tracking and diagnosis as well as outside agents (such as the decision frameworks developed in other PhD projects) is constructed in a standardized and transparent way.

The model is tested within some of the tasks addressed in each of the B1-B5 work packages. In this testing phase, particular attention is given to the possible combination of (sensor) data from multiple sources and the added value of this integration.

2.2 PhD 2: Methods for prioritization of alarms and intervention

2.2.1 Objectives and hypotheses

For this PhD project the specific objective is to contribute to the model based production and welfare monitoring by developing and improving methods for prioritization of alarms and intervention.

It is the hypothesis that by combining information from many different automatic and non-automatic sources it will be possible to reduce the number of false alarms from the monitoring system and thus avoid unnecessary (and potentially harmful) interventions.

2.2.2 Background, state-of-the-art and relevance

The improved options for monitoring data from many different data sources have a built-in risk of generating too many false alarms. Even when only one time series is monitored, the number of false positives may be a problem even in cases where the specificity of the detection method is very high. This was for instance a problem with an automatic heat detection method (Ostersen et al., 2010) for sows returning to oestrus with specificity around 99%. Nevertheless, the error rate defined as the ratio of false positive out of all alarms exceeded 95%. This is a natural consequence of sows returning to oestrus being a relatively rare event.

When furthermore time series from different data sources are monitored simultaneously there is an even higher risk of false alarms. Only some of the raw alarms will, therefore, require intervention and it is important to combine information from several data sources in order to reduce the number of false alarms. One option is to build multivariate monitoring methods integrating several time series into the same model and in that way improve the pattern recognition ability in the detection of undesired states like tail biting, diarrhea, undesired excretory behavior or impaired productivity.

Another option is integrate other kinds of (often non-automatic) information. The idea can be illustrated through an example of monitoring water intake of growing pigs (Madsen and Kristensen, 2005; Madsen et al., 2005). The monitoring technique used is a Dynamic Linear Model with diurnal variation in combination with a Cusum and a V-mask. If the system signals an alarm it is not necessarily because of a critical state of the pigs, but it may also be caused by other circumstances. If the monitoring system is integrated into the full data and management infrastructure of the herd, a systematic search for other causes can be done, e.g.:

- The process computer of the feeding system will have information about known irregularities concerning feeding.
- The herd database will have information about pigs inserted or removed from the pen or section.
- The process computer of the climate control system will have information about deviations in the climatic conditions.
- The herd database will know the date of insertion of the pigs. This information will influence the prior probability of diarrhea.

The decision to intervene will be based on the expected consequences for welfare and productivity combined with the strength and validity of the individual alarms.

2.2.3 Research plan and methods

For a suitable real time monitoring of data from several sources the necessary communication protocols and data infra structure must have been established. This is ensured through other parts of the PigIT project.

The PhD project will consist of the following elements:

- In collaboration with the other parts of the PigIT project a number of data sources are selected for proof of concept.
- Establishment of time series monitoring of individual data streams in close collaboration with PhD 1 and senior staff working with Work Package B.1. Relevant methods are expected to be state space models combined with methods from statistical quality control. For each data stream the following tasks are completed:
  - Structured data models are developed.
  - Variance components are estimated (EM algorithm, MCMC or similar methods).
  - Methods for detection of out-of-control cases (alarms) are developed (CuSums or similar).
  - Possible classification of data patterns corresponding to different causes of alarms.
- Development of causal models describing possible reasons for alarms. The causal models are expected to be based on probabilistic expert systems like Bayesian networks. This task is performed in collaboration with senior staff working with Work Packages B.2-B.4.
- Development of causal models describing possible consequences for productivity and welfare of the pigs. This activity will be closely coordinated with the relevant work packages of the PigIT project. This task is performed in collaboration with senior staff working with Work Packages B.2-B.4.
- Estimation of parameters of the causal models based on large amounts of data continuously collected in the PigIT project. Potentials for implementation of various learning methods from data will be studied.
- Integration of the causal models into the full data and management infrastructure of the herd so that information from different parts of production can be combined in a consistent way and used for the prioritization.
- Calibration of the method.
- Development of a generic concept which can implemented on other data sources.

The overall system is expected to be based on a Bayesian approach as for instance graphical models receiving the signals, messages and alarms from process computers, sensors, and staff. The system should be able to process the messages, and either store them or transfer them to the person responsible for reaction to the message. The urgency of the messages will differ, and the program should be able to take this into account. Depending on the urgency the person may be contacted via e mail on mobile telephone or via personal action list that may be read when the person logs on to the farm intra net.

The pig farms are currently increasing in size, and may be geographically distributed on several locations. The family farm is no longer the norm, and the typical production unit has several people involved with different responsibilities. An important issue is not so much, how to contact the farmer but rather how to reduce the number of acute alarms and to secure that only the person responsible receives the alarm.

The system should be easily configurable, even from remote equipment, so that the farmer may switch the address of certain types of messages to a different person. Optionally the program can contact the person closest to the problem.

2.3 PhD 3: Optimization methods in a stochastic production environment.

2.3.1 Objectives and hypotheses

For this PhD project the specific objective is to contribute to model based decision support by developing and improving methods for making economic optimal decisions at both pen and herd level and at the same time consider animal welfare.

It is the hypothesis that by combining model based decision support and sensor information better economic decisions can be taken with a lower risk.

2.3.2 Background, state-of-the-art and relevance

In most cases decision models are optimized using deterministic parameters. However, if the modelled system is very stochastic, a model with stochastic parameters is more realistic but often harder to optimize. Pig production systems have a very stochastic nature and hence stochastic models are often suitable.

Relevant decisions include marketing decisions. Here models can be based on "offline" weight curves (Jørgensen, 1993; Kure, 1997; Niemi, 2006; Ohlmann and Jones, 2008) or sensor information can be used (Kristensen et al., 2012). Feeding strategies are also very important (Niemi, 2006; Parsons et al., 2007; PomarI et al., 2009).

Decision support related to infectious diseases is also relevant (Toft et al., 2005). Diarrhea causes increased pain and discomfort and the production is affected with reduced growth and reduced feed intake. This may result in more frequent outbreaks of tail biting and increased use of antibiotic. If diarrhea can be detected early by sensors, early medication at pen level can be done. The length of the cleaning period of the barn/section after marketing also affects the risk of infectious diseases.

Another major problem is tail biting which causes pain and increased risk of diseases. As a result more time is spent sorting and isolating pigs. This may result in poor growth, increased use of antibiotic and tail docking at herd level. If the state can be detected early by sensors interventions at pen level may be possible e.g. increased straw from 10 g to 100 per pig per day or reduced stocking rate with 2 pigs per pen.

A special challenge in relation to decision support models is how to integrate decisions at animal, pen, section and herd level. Decisions at one level (e.g. animal or pen) must be linked to the capacity constraints at a higher level (e.g. section or herd). In addition, the decisions concerning intervention to avoid welfare and productivity problems will often face different constraints and time horizons, than those aiming at optimizing an on-going production. As a result a model optimizing on all levels simultaneously may be too complex. Thus, there may be a need for approximate methods, which e.g. relax the requirement of an optimal solution and search for a better than current solution.

2.3.3 Research plan and methods

The preliminary plans for the PhD project are:

- A literature review over the state of the art for pig farming decision models.
- A model for optimal dynamic allocation of pigs to the different feeding areas.
- A model for optimal feeding level in groups and marketing of individual pigs for slaughter.
- A model calculating different intervention strategies for tail biting based on different objectives (economy, welfare, etc).
- A model optimizing over different levels simultaneously.

Parameters and forecast models used in the decision support models are ensured through other parts of the PigIT project.

The expected methodologies used (but not limited to) are Markov decision processes (ordinary and hierarchical), dynamic programming, (stochastic) linear/integer programming and simulation. Under all methodologies multiple criteria might be considered.

2.4 PhD 4: Evolutionary operations as a tool for improving welfare and productivity

2.4.1 Objective and hypotheses

For this PhD project the specific objective is to contribute to the overall aim by adapting and applying statistical methods from industrial process optimization, such as evolutionary operations (EVOP) to the production of growing pigs.

As mentioned, the overall hypothesis of PigIT that a systematic placement of cheap sensors in the production pens combined with methodological developments to integrate the information from these sensors will improve the production process and thus add significant value to investment in the sensor technology. An important aspect to gain the full benefit from this is to use a systematic approach to varying the production factors in order to find the optimal combination of these in each herd.

For this subproject the hypothesis is the use of the sensor information ensures that the designed systematic adjustment of production factors and evaluation of the effect on the production can be done with minimal extra efforts. This will make the application of EVOP a feasible option in pig farms. However the special characteristics of the pig production process, such as a large variation between production batches, and the long duration of producing one batch requires modification of the setup used for industrial processes.

2.4.2 Background, state-of-the-art and relevance

The major welfare problems affecting the productivity of growing and finishing pigs in the introduction are very often multi-factorial, with large differences between herds, and only a little understand of the causal mechanism behind the problem in each herd. As examples, the causes of both tail biting and undesired excretory behaviors are currently unclear and seems to vary from herd to herd, which makes it difficult to take action to tackle and prevent these welfare issues. Tail docking, which is a painful intervention to prevent tail biting, is only allowed in herds with severe tail biting problems. However, tail biting is currently so common, that tail docking is almost routine practice. Indeed, a better understanding of the causes of tail biting in each herd is necessary to avoid both its occurrence and also the practice of tail docking. Implementation of systematic approaches for process optimization within the herds seems like an obvious choice in order to identify the important factors for the occurrence of these welfare and productivity issues.

Though it is well known that farmers like to experiment with different production technology, there has never been an attempt to systematizing this approach. Furthermore, because of the number of production units, and the large variability, the recording and data analyzing has been too costly to be implemented on a regular scale. Systems for automatic data recording will reduce these costs significantly.

As discussed above, simple sensors are already installed on many pig farms (e.g. temperature, water and feed). By adding more a few more sensors plus a by using a systematic approach to the positioning of the sensor promise to add new dimension to the use of the information from the sensors, both with respect to how different parts of production systems function, which types of problems that may be detected, and how the information may be used for a dynamic fine tuning of the production process. This concerns productivity, behavior and climate regulation. Thus the animal behavior observations that the farmer rely on can to a large extent be replaced by automatic registrations concerning activity coming from sensors such as water meters, video recordings and passive infrared sensors. Because these registrations are available on a continuous time scale, they will contribute information about diurnal rhythm in activity and resource use, information that is not available from observations of the farm by the farmers.

All these information sources can be included in the data analysis used in the EVOP process.

To use the EVOP technique it is a necessary to increase the knowledge about the different sources of variation in the measured variable, and how this should be reflected in the statistical designs that will be used in EVOPs implementation. It is necessary to describe a framework for the how the farmer can be helped in identifying the most important factors to study in the experiments.

2.4.3 Research plan and methods

The development of the EVOP will take place in close contact with 2-4 production herds where the principles can be applied through the project period. In addition, for a suitable use of EVOP the necessary communication protocols and data infrastructure must have been established. These requirements are ensured through other parts of the PigIT project.

The PhD project will consist of the following elements:

- In collaboration with the other parts of the PigIT project a number of data sources are selected for proof of concept.
- Establishment of industrial EVOP experiments in 2-4 case herds together with farm management with focus on factors that will influence the occurrence of welfare related behavioral problems.
- Potential designs in typical pig herds are defined.
- Evaluate the potential for EVOP based on literature review, optionally supplemented by simulation study.
- Design optimization for sequential designs with the variability and restrictions due to the production system, e.g. the duration of each experimental phase or the selection of factors to vary at the section level and with the section at the pen level. Simulation studies will be used.
- Compare use of EVOP without sensors, sensor information at the section level, pen level and individual level as experimental units based on simulation studies.
- Implementation of designs with focus on establishing documentation of when treatments such as medication and tail-docking may be stopped.

The primary task will be to adapt existing methods from the industry into the specific requirements of growing pigs, both with regards to the statistical designs, and also concerning the selection of which production factors to vary. In contact with the farmers these adaptations will be implemented in the case herds. During the experimental phase, simulation studies of the design possibilities will be conducted and methods for analyzing the data implemented. Finally the outcome from the herds will be analyzed, and the next step in the optimization process defined.

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