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Concept of key performance indicators controlling consumer oriented quality and herd health management in a Bavarian pork chain.

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Abstract

Concept of key performance indicators controlling consumer oriented quality and herd health management in a Bavarian pork chain.

The aim of the present thesis was to develop a concept of key performance indicators (KPIs) for a Bavarian pig cooperative regarding the benchmark of farms and controlling KPIs. The thesis structure follows a pseudo-cumulative work consisting of a general introduction, four independent chapters and a general conclusion.

The developed concept based on results of an experimental and empirical study of four fattening periods conducted at 20 pig farms in Southeast Bavaria. 10,226 pigs were assessed on porcine respiratory disease complex (PRDC) health status through different parameters. 587 blood samples were collected at slaughter and analyzed with ELISA serological tests on five pathogens associated with PRDC. Technical performance data of 78 fattening periods were available.

A new serological indicator (SI) was developed, summarizing the overall sera reactivity per herd by one value and indicating the farm pathogen pressure. The SI enabled a benchmark of farms on the pathogen pressure. The value of the SI was significant correlated with defined KPIs. KPIs were the respiratory health status, usage of antibiotics, clinical symptoms, average daily growth rate, feed conversion rate and gross margin per stable place. The two most relevant pathogens influencing the KPIs were porcine reproductive and respiratory syndrome virus and *Actinobacillus pleuropneumoniae serotype 2*.

The designed benchmark based on two new KPIs, technical performance and respiratory health. The benchmark enabled an inter-organizational benchmark of fattening period as well as an intra-organizational benchmark of the members of the cooperative. In order to continuously improve animal health and thus to improve the defined KPIs, the developed controlling concept based on four elements: (1) regional defined pathogen pattern (2) serological indicator and farm specific serological profile (3) organizational merging of data in a two dimensional benchmark of animal health and technical performance (4) interpretation guide through the developed enzootic risk matrix.

Kurzfassung

Konzept von Key Performance Indikatoren für das Controlling eines kundenorientierten Qualitäts- und Gesundheitsmanagement in einer bayerischen Schweinefleischkette.

Das Ziel der vorliegenden Arbeit war es, ein Konzept von Key Performance Indikatoren (KPI) für das Benchmark und das Controlling von Betrieben in einer bayerischen Erzeugergemeinschaft für Schweinefleisch zu entwickeln. Die Arbeit folgt einer pseudo-kumulativen Struktur, bestehend aus einer allgemeinen Einführung, vier unabhängigen Kapiteln und einer allgemeinen Schlussfolgerung. Der erarbeitete Konzeptvorschlag basiert auf Ergebnissen einer experimentellen und empirischen Untersuchung von vier Mastdurchgängen in 20 südostbayerischen Schweinemastbetrieben. Von 10.226 Mastschweinen wurde der Lungengesundheitsstatus anhand von unterschiedlichen Befundkategorien beurteilt. Insgesamt wurden 587 Blutproben bei der Schlachtung genommen. Die Proben wurden mit serologischen ELISA Tests auf Antikörper gegen fünf Pathogene untersucht, die im Zusammenhang mit der Lungengesundheit stehen. Insgesamt standen technische Leistungsdaten von 78 Mastdurchgängen zur Verfügung.

Die Einzellaborbefunde wurden im neu entwickelten Serologieindikator zusammengefasst. Dieser Wert ist Maß für den Erregerdruck im Bestand und stellt einen neuen KPI zur Einstufung von Schweinemastbetrieben dar. Die Höhe des Serologieindikators korrelierte mit den definierten KPIs. KPIs waren der Umfang des Einsatzes von Antibiotika, die Prävalenz von klinischen Symptomen, die biologischen Kenngrößen, bestehend aus Tageszunahmen und Futterverwertung, und die ökonomische Kenngröße, Bruttomarge in € je Stallplatz. Die KPIs wurden am stärksten durch das Porzines Reproduktives und Respiratorisches Syndrom Virus und den Actinobacillus pleuropneumoniae Serotyp 2 beeinflusst.

Das konzipierte Benchmark, basierend auf zwei neu entwickelten KPIs, erlaubt sowohl den betrieblichen als auch den überbetrieblichen Vergleich hinsichtlich biologischen und auch tiergesundheitlichen Kenngrößen. Um die Tiergesundheit kontinuierlich zu verbessern und somit die definierten KPIs nachhaltig zu steigern, wurde ein Controlling bestehend aus den vier folgenden Elementen entwickelt: (1) Regional definiertes Erregermuster (2) Serologieindikator und betriebsspezifisches Serologieprofil (3) Organisatorische Zusammenführung von Daten in einem zweidimensionalen Benchmark von Tiergesundheit und Mastleistung (4) Beratung und Sensibilisierung durch die entwickelte enzootische Risikomatrix.

Content

List of abbreviations

ADGR	Average daily growth rate
AFCR	Average feed conversion rate
ANOVA	Analysis of Variance
APP2	*Actinobacillus pleuropneumoniae serotype 2*
CIP	Continuous improvement process
DMAIC	Define – Mesaure – Analyze – Improve – Control
e.g.	Exempli gratia
ELISA	Enzyme Linked Immunosorbent Assay
EU	European Union
FMEA	Failure Mode and Effects Analysis
KPI	Key performance indicator
Mhyo	*Mycoplasma hyopneumoniae*
Mngt	Management
PCV	Pork value chain
PCV2	Porcine circovirus type 2
PRDC	Porcine respiratory disease complex
PRRSV	Porcine reproductive and respiratory syndrome virus
QS	QS Qualität und Sicherheit GmbH
SE	Standard error of regression parameters
SI	Serological indicator
SIV	Swine influenza virus
TIGA	Tiergesundheitsagentur

Chapter 1 - General introduction

1.1 Introduction

Today pork chain actors are active in an area of tension between social demand and economic livelihood. The requirements of and for the modern pig production are in a continuous movement and increase. Currently a great challenge is the reduction of antibiotics usage with simultaneous consideration of animal health as well as animal welfare. Additionally, the economic livelihood of farmers is confronted with increasing market prices for production materials. A prerequisite for profitable production, for food safety and for animal welfare is an optimal pig herd health status (Maes, 2013).

A performance indicator or key performance indicator (KPI) is a type of performance measurement. A performance indicator can be defined as an item of information collected at regular intervals to track the performance (Fitz-Gibbon, 1990). One of the most cited definitions of KPI was formulated by Parmenter (2010): KPI describes the measures to take to increase performance significantly. KPIs usually are long-term considerations. KPIs are used by an organization to assess the success for a particular activity. Success is defined as making progress towards defined strategic goals (Parmenter, 2010). Further, it is the repeated achievement of operational goals (i.e. zero defects or 100% healthy pigs). The challenge of an organization or in the present case a chain is to define the most relevant KPIs. Therefore, it is crucial for chain actors to control those KPIs. Controlling is a process measuring current performance and through controlling measures defined objectives can be reached (Boes, 2006). It is common practice to use traditional KPIs for benchmarking purposes. In practice, overseeing KPIs can prove expensive or difficult for organizations (Fitz-Gibbon, 1990).

Performance in pig production is traditionally measured using KPIs as well. Popular KPIs are feed conversion rate, average daily growth rate and production costs as well as labor income (Meesensel et al., 2010). However, some KPIs are currently overseen as the animal health status or the pathogen pressure on farm (LKV, 2011). The economic impact of one pathogen, for example porcine reproductive and respiratory syndrome virus, is high. The occurrence decreases the reproduction rate in breeding herds, increases the mortality rate and leads to inefficient technical herd performance. Still today the porcine respiratory disease complex (PRDC) results in high economic losses in modern pig production because of reduced growth rate, decreased feed conversion (Grest et al., 1997, Martinez et al., 2009, Martelli et al., 2009), increased medical costs, and adverse effects on pig welfare (Sorensen et al., 2006). Pneumonia leads to a decrease of average daily growth rate between 19 g and 54 g (Berns, 1996). In addition, the usage of antibiotics to treat lung diseases is considered a downstream human health risk (Anderson, 2003).

A need for improvement in the pig production is the circumstance that the prevalence figures of lung lesions in slaughter pigs, indicating the pig health status, are comparable to those of 20 years ago (Maes, 2013). In conclusion, to reach a continuously satisfying health status without PRDC is a key success factor to improve the economy of pig production, food safety and animal health. However, a dramatically change is hampered due to the fact that PRDC is multi-factorial and subclinical. Frequent monitoring of pathogens associated with the PRDC such as *Mycoplasma hyopneumoniae* (Mhyo), *Actinobacillus pleuropneumoniae serotype 2* (APP 2), swine influenza virus (SIV), porcine reproductive and respiratory syndrome virus (PRRSV), and porcine circovirus type 2 (PCV2) is a possible solution. The pork health management systems in the Netherlands, Denmark and Germany are focused on those pathogens. The considered farm levels in those pork health management systems are mainly breeding and rearing. Only one out of eight health management systems considers the farm level fattening (Schütz et al., 2012). Schütz (2009) and Ellebrecht (2012) identified a high interest of farmers to assess their pig herd health status through the participation in monitoring programs. Health monitoring has become much more critical for a profitable and sustainable pig production (Maes, 2013). Meat juice or blood, on farm or at slaughter, can be used in four diagnostic areas, first notifiable diseases, second production diseases and third food safety related diseases and zoonoses (Blaha and Meemken, 2011). The fourth diagnostic area is non-specific marker of inflammation (Knura-Deszczka, 2000, Petersen et al., 2000, Klauke, 2012, Klauke et al, 2013).

In recent years, the interest has significantly increased to support and to implement an intra- and inter-organizational quality management system in pork value chains through the installation of chain wide information and communication systems (Schiefer, 2003, Horvath, 2004, Pfeiffer, 2005, Poignée et al., 2005, Mack et al., 2005, Ellebrecht, 2008). Those systems are needed to communicate the results of the inspection, i.e. on health status. The exchange of information, regardless of the objective, is essential in a solid agri-food supply chain (Ballou et al. 2000, Ketikidis et al., 2008). Therefore, coordinating organizations are needed which ensure the exchange of information to support the continuous improvement process on KPIs (Brinkmann et al. 2011). The information exchange is a key success factor. Hereby, production related chain prevention and treatment measures are becoming more efficient (Schütz, 2009). However, there is lack of communication, the customers often do not know which inspection have already been performed on the product and which results occurred (Lang and Petersen, 2012, O'Hagan et al., 2013). Due to competitive advantage and the expectation of reprisals information are not public and are tacit knowledge of the executing stage. The results of monitoring notifiable diseases, production diseases and food safety related diseases as well as zoonoses are hardly communicated with the chain actors and along the meat chain (Meemken and Blaha, 2011). Only by law described information, though the amount is limited, are exchanged between partners.

Incentive mechanisms are recommended for animal health control on farm level (van Wagenberg, 2010) and should be enlarged on chain level. An aggregate of million € figure is impressive at the national level to prevent and contain production diseases. However, it is not a guarantee that sufficient incentives exists for the farmer to adapt control strategies for production diseases if made available. If farmers do not see an early break even between appraisal costs and prevention costs then the participation in the monitoring program is hampered. However, monitoring is essential to derive precise measure to improve pig herd health status significantly.

1.2 Research objectives

The aim of the present thesis is to develop a concept of KPIs controlling consumer oriented quality and herd health management in a Bavarian pork value chain. This raises in particular the question of which KPIS to use and where to gather the necessary data for them, in order to enable specific measures to increase the pig herd health status significantly and to improve the production according to consumer oriented quality expectations. For this purpose the following hypothesis were tested:

The present thesis is testing the following four hypotheses:

1. The value of information for monitoring and testing strategies to promote the continuous improvement process can be explained by the combination of quality tools, processes and tasks in a three shell continuous improvement process model. (Chapter 2)
2. A monitoring and testing strategy based on blood sampled at slaughter is suitable for interpretation of KPI. (Chapter 3)
3. The monitoring and testing strategy enables to explain the financial impact of production diseases on farm level and that the benefits of this strategy outweigh the costs. (Chapter 4)
4. The combination of health parameters and fattening performance parameters is suitable for implementation of on farm and inter-organizational benchmarks and allows the identification of vulnerabilities. (Chapter 5)

To prove the hypotheses, the present research uses the following outline.

1.3 Outline of the thesis

The introduction and problem description is pointed out in chapter one (figure 1). Chapter two presents the three shells continuous improvement process model to gather target information in order to promote the continuous improvement process for social or economical tasks, which the pork production is facing. In chapter three the relationship between the information gained through the analysis of blood sampled at slaughter and KPIs such as clinical symptoms of pigs prior to slaughter, percentage of pigs with pneumonia assessed during meat inspection, average daily growth rate, feed conversion rate and usage of antibiotics is assessed. The relationships were validated in three additional fattening periods. In chapter four the financial analysis of the monitoring and inspection strategies to control KPIs is done. In chapter five a two dimensional farm level benchmark is developed based on two KPIs, in detail KPI on technical performance and respiratory health. Finally, chapter six integrates the findings in the general conclusion.

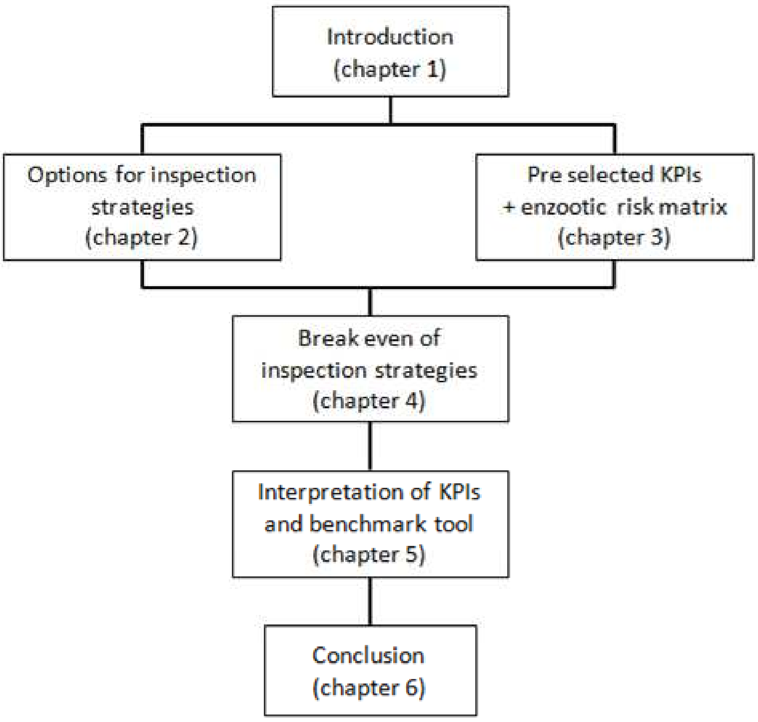

Figure 1.1 Outline of the thesis

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Chapter 2 - Model to predict the information gain of specific monitoring and inspection strategies in pork chains

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2.1 Abstract

Social tensions and economic livelihood increases the demand to gather the most efficient information to answer the appearing questions and hereby to control the key performance indicators such as usage of antibiotics or average daily growth rate. Information has become cheaper and is gathered at many points along the supply chain. A disadvantage is that nearly all chain actors will be overwhelmed by an unstructured information flood. The purpose of this chapter is to configure a framework that enables the target collection of information necessary for the continuous improvement process in pork value chains.

A three stage research strategy was employed. First, via case study, qualitative primary data were gathered to investigate the Southeast Bavarian pork value chain and their knowledge exchanging state of the art. The second stage comprises a desk research including already established tools and approaches to gather specific information relevant to the demands in the pork value chains. In the third stage one was presented that validate the practical application of the derived three layer continuous improvement model and the estimation of the value of the information.

First, in the Southeast Bavarian pork value chain a lot of information are tacit knowledge, such regarding pig health status or usage of antibiotics. Only information prescribed by law are exchanged. Second, the established three shells continuous improvement model enables to increase the efficiency to collect most suitable information for solving the demands in pork value chain. A structured approach is possible, supported by predefined questions. Third, the applicability of the three shells continuous improvement process model is applied on the objective of reducing the usage of antibiotics in pork production.

Users of the model, mainly net-chain coordinators, are enabled to predict the creation of value through additional information in advance and can assess the support performance regarding issues of concern. The unique opportunity arises to assess which information to gather and by this to promote the continuous improvement process of the entire pork value chain.

2.2 Introduction

Access and ownership of knowledge is, first, a source of power (Desouza, 2003 and Davenport and Prusak, 1998), second, a critical success factor to reach competitive advantage (King and Zeithalm, 2003). Knowledge roots on information. Forrester (1962) defines information as *"the substance from which the managerial decisions are made"*. Knowledge management in agri-food supply chains received over the last decades an important role (Schütz 2009, Ellebrecht 2008, Schulze-Althoff, 2006). Knowledge transfer between chain actors is getting more and more important in demanding agri-food chains (Schulze-Althoff, 2006). Bijman (2002) defines agri-food chains, where agricultural products go through different stages of production and distribution before being placed on the shelf space, where the final consumer can buy it.

Knowledge and information are dynamic resources that need to be managed carefully in those chains (Massa and Testa, 2009). For achieving mutual benefits, companies active in agri-food supply chains should cooperate (Vlachos, 2003, Haygena, 2000, Ghisi and Silva, 2001). By sharing information the opportunity arises, that all chain participants receive mutual benefit (Schütz, 2009). A solid agri-food supply chain bases on information and a transparent knowledge exchange (Ballou et al. 2000, Ketikidis et al., 2008). Information sharing through a knowledge exchange management system is defined as the extent to which critical information are exchanged with the supply chain partners (Monczka et al, 1998). Information sharing can be assessed as one of the five blocks that characterize a solid supply chain (Lalonde, 1998). More important than information sharing is the information quality. Li and Lin (2006) summarize such aspects *"as the accuracy, timeliness, adequacy, and credibility of information"* of information quality. Moreover, the influence of the information on the supply chain depends on the information itself. Additionally, when and how and with whom the information is shared determines the quality as well (Chizzo, 1998).

In the last decades information has become cheaper and information are gathered at many points along the supply chain (Lang und Petersen, 2012). The danger arises that nearly all chain actors will be overwhelmed by an information flood. Worst case, information is not used for the continuous improvement process.

The inadequacies of information and overwhelmed by details could be overcome by *"an organized process for integrating all available knowledge into comprehensive plans that can* *be systematically implemented"* (Sosnicki and Newman, 2010). Further, the adequate implementation of an information and communication system enables to avoid an overpowering (Schütz, 2009, Ellebrecht, 2008). Net-chain coordinators have established information and communication systems to enable upstream and downstream information flow and to promote knowledge management (Schulze-Althoff, 2006, Elllebrecht, 2008, Schütz, 2009).

This chapter elaborates to configure a model that enables the target collection of information for specific monitoring and inspection strategies of KPIs that are necessary for the continuous improvement process in pork value chains and by this to avoid an overpowering of information and to collect only targeted information.

This chapter is testing the first hypothesis: The value of information for monitoring and testing strategies to promote the continuous improvement process can be explained by the combination of quality tools, processes and tasks in a three shell continuous improvement process model.

2.3 Material and method

2.3.1 Southeast Bavarian Pork Value Chain and its information and communication structure

The present research objective is the Southeast Bavarian pork value chain. According to Porter (1996) the generic value chain concept consists of primary and support activities. Primary activities are inbound and outbound logistics, operations, marketing and sales as well as service. Support activities are firm structure, human resource management, technology and procurement. The Southeast Bavarian pork value chain consists of eight primary and seven secondary activities to produce pork (figure 2.1). Five out the eight value chains, breeding, rearing, finishing, meat center and retail, are directly involved in the production process of pork. Indirectly three value chains are involved, livestock traders, feed and medical producers.

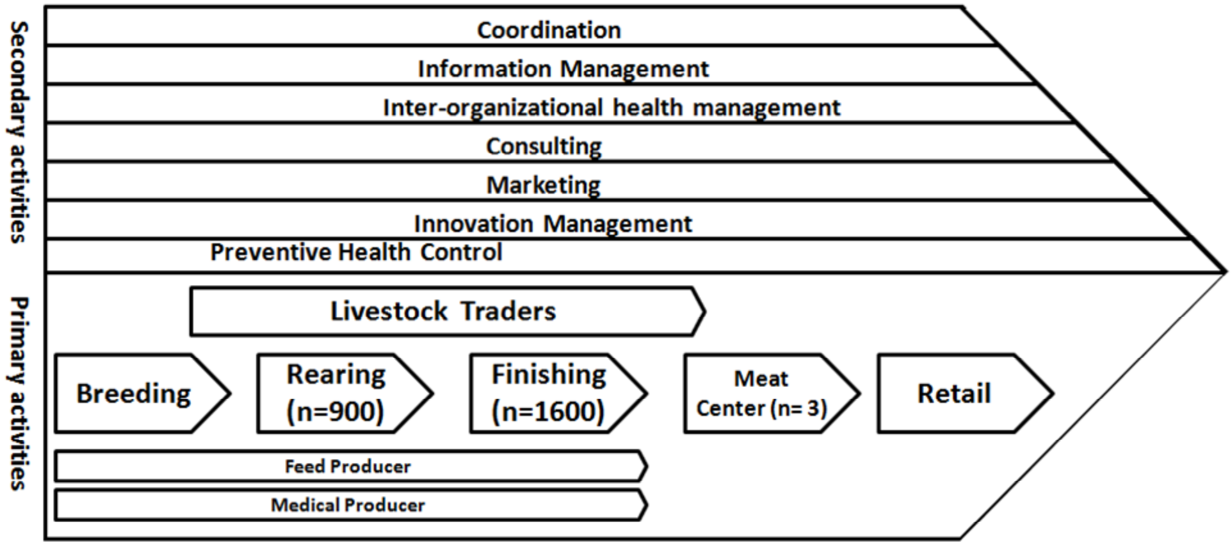

Figure 2.1 Structure of Southeast Bavarian pork value chain

In the Southeast Bavarian pork value chain the net-chain coordinator is the livestock trader, grower association Southeast Bavaria, one of the largest cooperative in Bavaria. The cooperative bundles the interest of app. 10,000 members. An in-depth view was taken on the business unit pork. Here 900 piglet producers and 1600 fatteners are coordinated. A unique circumstance, the grower association holds shares of three slaughterhouses, which slaughter 1.1 Mio. pigs produced in the investigated pork value chain. The core activity of the grower association is livestock trading, between breeding level, rearing level, finishing level and meat center. Therefore, the activities between the four chain actors are bundled. Feed and medical producers are not coordinated by the net-chain coordinator and also no centralized buying is offered or conducted. The six identified secondary activities are located at the net-chain coordinator. Information management promotes forward and backward information flow along the chain. One central information and communication system is used. This enables exchange of knowledge between the participants (figure 2.2) and the definition of access rights (table 2.1). The implemented inter-organizational health management consists of the defined items: 1) health control 2) herd diagnostic analysis 3) environment analysis 4) government supervision 5) exchange of food chain information 6) epidemiological monitoring 7) creating preliminary report 8) early warning system 9) certification. Consulting is focused on preventive health control through veterinarians and the reduction of antibiotics usage. The cooperative uses marketing as quality communication within the chain and at point of sale. The primary purpose of innovation management is to introduce change in the organization, with the ambition to create new opportunities to meet the market demands. According to the definitions given by Schütz (2009) the grower association Southeast Bavaria can be described as a full-service provider.

The analysis of gathered information and shared knowledge displayed that on each level of the investigated pork value chain information are available and a lot of brain monopoly exists (table 2.1). Figure 2.2 shows the information management system.

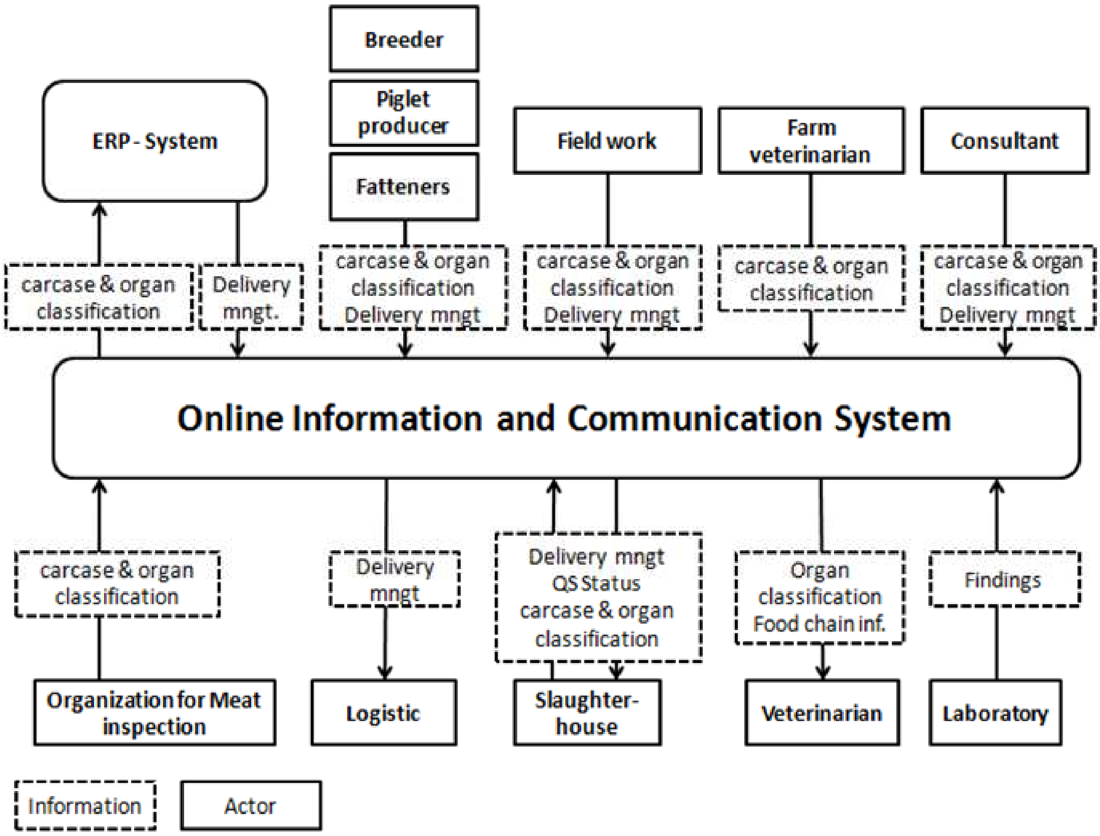

Figure 2.2 Current information communication system in the Southeast Bavarian pork value chain

The core of the information and communication system is an online information and communication system organized and maintained by a neutral organization. Mainly carcass and organ classification results are frequently exchanged with different chain actors. Due to predicted by law (table 2.1). Further, these are digital data which can be easily exchanged between the actors. Additionally, process numbers, such as quantity of animals, delivery date and etcetera are exchanged. This is also true for the laboratory uploads findings regarding Salmonella. Currently, only information on carcass and organ classifications as well as salmonella can be used for the continuous improvement process.

Table 2.1 State of the art in the exchange of information between the chain actors in the Southeast Bavarian pork value chain

Chain Actor	Information: Carcass classification (e.g. Lean meat content)	Organ classification	Audit results (QS & others)	Delivery Information (e.g. quantity, delivery date)	Food chain information	Animal Health Status	Salmonella status	Usage of antibiotics	Vaccination status sows & piglets	Animal diseases breading, rearing and finishing level
Breeder			(X)			O		O	O	O
Piglet producer			(X)			O		O	O	O
Fatteners	X	X	(X)	X	X	O	X	O	O	O
Animal trader	(X)	(X)	(X)	X						
Logistic				X						
Slaughterhouse	X	X		X	X		X			
Veterinarian	(X)	X	(X)	X				O		
Farm Veterinarian	(X)	(X)	(X)			O		O		
Consultant	(X)	(X)	(X)					O		
Laboratory							X			

X information exchange (X) potential information exchange with permission O none information exchange

A large black box on animal health status, drugs applications and vaccination status of sows and piglets and occurred animal diseases during fattening was identified (Table 2.1). Those information are tacit knowledge and only available on farm level. However, those data are not digitalized. Digital information are more likely to be exchanged with permission as not digitized information such as drug application or vaccination status. However, some animal diseases are sometimes not known by farmers, because they are subclinical. Therefore, the knowledge cannot be exchanged with buyer of piglets or sows. The result is information asymmetry.

2.3.2 Definition of levels of a continuous improvement process model

The desk research on quality management tools leads to the conclusion that the development of a three shells model best suits the target to assess potential new information for monitoring and inspection strategies of KPIs. The three shells can be defined as process, tasks and tools. In the three shells continuous model quality management relevant tools are included such as the Define - Measure - Analyze - Improve - Control (DMAIC) cycle, demand analysis, house of quality, statistic process control, quality control chart, Failure Mode and Effects Analysis (FMEA) and decision tree analysis.

2.3.3 Definition of the score model to estimate the value of information for the continuous improvement process

Ellebrecht (2008) developed a model that calculates benefits of inter-organizational communications and information systems for different actors in the pork value chain. For the benefit assessment of those systems Ellebrecht (2008) selected four characteristics: 1. gain in time 2. information growth 3. degree of closeness and 4. time to decision (table 2.2). Schütz (2009) added to those three more qualities: 5. degree of traceability 6. degree of utility expectation and 7. degree of willingness to share information (table 2.2). These seven characteristics enable to determine the benefit of inter-organizational communication and information systems. However, Schulze-Althoff (2006) stated that in a pork value chain many actors are involved. Consequently, the degree of coverage of chain actors in information and communication systems is added. Petersen and Nüssel (2013) used those criteria as well. The bundle of characteristics describing the benefits of inter-organization information and communication systems will be used to assess the benefit or value of individual information that is under investigation for the usage in a monitoring and inspection strategy to control KPIs. To assess the value of individual information the model parameters were adapted to this circumstance (table 2.2).

Table 2.2 Definition of the six variables with categories and coded values of the score model to estimate the value of information for the continuous improvement process

Variables	Categories	Value
A: Gain in time to derive the right decision	None	0
	Very low	25
	Low	50
	High	75
	Very high	100
B: Information growth	not digitized data	0
	digitized data (dd) + descriptive information (di)	25
	dd + di + comparative information (ci)	50
	dd + di + ci + predictive information (pi)	75
	dd + di + ci + pi + prescribing information	100
C: Time to decision	One year	0
	Half or quarter of year	25
	7 – 14 days	50
	1 – 5 days	75
	< one day	100
D: Degree of potential exchange partners	None	0
	1 – 4	25
	5 – 8	50
	9 – 12	75
	≥13	100
E: Degree of traceability	Chain level	0
	Farm level	25
	Stable level	50
	Batch level	75
	Animal level	100
F: Degree of utility expectation for the solution compared to current situation	None	0
	Very little	25
	Little	50
	High	75
	Very high	100

Gain in time is saved time through additional information or tacit knowledge transformed in open knowledge. Information growth is defined as increase of knowledge for each chain actor. Time to decision is defined as time based on information instead without to take the right decision. Important to know is the degree of willingness to exchange information, the degree of potential exchange partners. To be useful the value of additional information or tacit knowledge for all chain actors must be higher than only downstream relevant. Further, willingness increases when the value for the continuous improvement process is identifiable. The value of information increases with the degree of traceability. Can the information be traced back to animal level the value is much higher compared to batch level. The degree of utility expectation expresses the net chain expatiation of the knowledge exchange for the entire PVC. Calculating the economic value in monetary term of knowledge exchange is hardly possible. Therefore, a score-model relating to the above highlighted parameters was developed. On this basis users calculate whether the gathered information and unlocked tacit knowledge is required for the continuous improvement process. The information value indicator ranks between zero and one. Through the following formula the information value indicator is calculated:

$$\frac{\text{VoV A + VoV B + VoV C + VoV D + VoV E + VoV F}}{\text{Maximum value of 600}}$$

VoV = Value of Variable

2.4 Results

2.4.1 Three shells continuous improvement process model

The core of the three shells continuous improvement process model is the DMAIC-cycle (figure 2.3). On the second layer the tasks are listed to be executed. The most suitable quality management tools are presented in the third layer. The model supports and promotes actors to gather only valuable information for the continuous improvement process and to avoid chain actors being overwhelmed by useless information or to avoid the investment in wrong information sources. Logically, the net-chain coordinator should use the decision support model.

In the first phase **"Define",** the task is to identify customer requirements and consequently to define the objective of the three shells continuous improvement process model. For this approach two tools are frequently used, the demand analysis and the house of quality. Different objectives are possible. The scope ranges from social to economic objectives. A social objective can be the reduction of antibiotics usage in pork production. Economic objectives are various, the overall goal is to maximize contribution margin. A second, the goal is for example to maximize piglets or porkers traded within the pork value chain. That means maximization of piglets/sow/year and minimization of losses through animal diseases. Third, a minor goal is for example the shortening of fattening period. Beyond this, in the "Define" phase the house of quality can be used to determine first the variables to focus on and second to determine upper and lower limits. Meat centers for example require pigs with 56 – 58 muscle meat share and weight between 82 and 105 kilo. Customer requirements are the upper and lower bounds of the quality control chart.

Define questions*: What demands the buyer group? What parameters define the demand?*

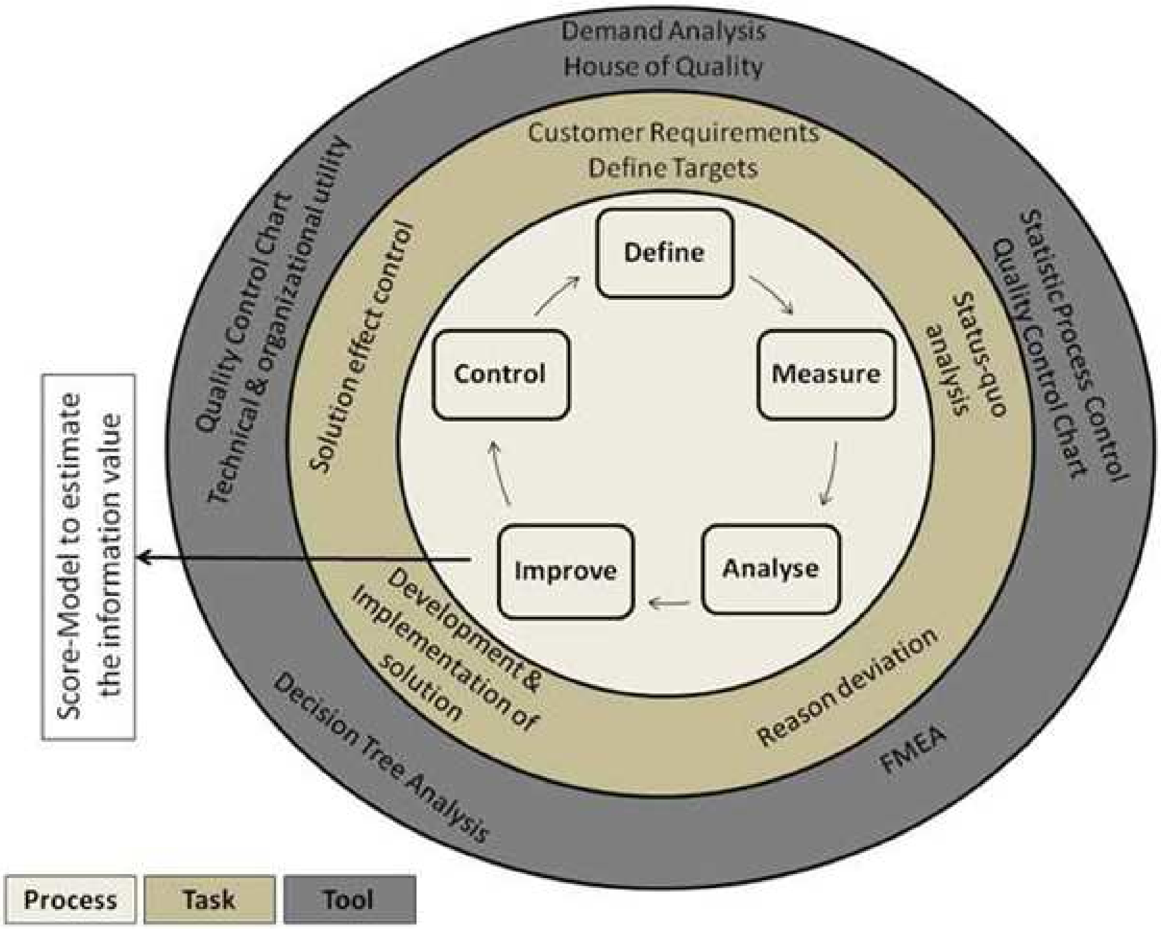

Figure 2.3 Three shells continuous improvement model with score model to estimate the information value

After requirements are clearly defined and transparent for each actor the **"Measure"** process can be started. The task is the status-quo analysis of KPIs that describe the predefined target. Therefore, different tools are used such as the statistic process control and the quality control chart. Quality control charts are already used in the agri-food business. The usage of quality control charts is mainly useful where online datasets are available.

Measure question: *Do the parameters fulfill the requirements?*

In the **“Analyze”**-phase the task is explained why the defined target is yet not reached. The Failure Mode and Effects Analysis (FMEA) is a suitable tool for this purpose. The risk priority numbers is calculated based on three parameters occurrence, severity and detectability. Occurrence is equal to morbidity. Severity is the mean of mortality, production influence, process limitations, duration of disease and treatment, finally trade restriction. The probability of detection is estimated.

Analyze question: *Why do the parameters not fulfill the requirements?*

The task in the **“Improve”** – phase is to develop and implement the most suitable solution. Therefore, the tool decision tree analysis can be used. As described earlier, agri-food chains in specific pork value chains are very dynamic and problems are mainly multi-factorial. Short, the decision tree visually presents the potential steps to be taken in the decision process. Consequently, the assessed knowledge or information leads to a decision, which change thinking and acting with the purpose to reach the defined target. For the implementation of the right solution mainly new information are necessary. The developed score-model to estimate the information value enables the estimation of the value of the information for the target.

Improve questions: *What to improve to reach the targets? What knowledge and information are needed to execute the right decision?*

In the **“Control”** –phase the task is to assess the effect of implemented decisions. As tools the quality control chart can be used.

The application of the three shells model is coordinated by the net-chain coordinator, in this case the grower association Southeast Bavaria.

2.4.2 Score model to estimate the value of information for a continuous improvement process

The score model was developed to estimate the value of information that is yet not there but very important for the continuous improvement process. The scoring model consists of the previous six criteria where each has a weight factor (table 2.2). The value of an information ranges between 0 and 600. In minimum zero points can be reached, which means the information does not contribute to the defined target. The maximum value is 600. The information value indicator can be calculated by dividing the results of the score-model by the maximum (table 2.3).

Table 2.3 Information value indicator

Information value indicator	Decision
0 – 0.33	Information should not be gathered, as there is no value expectation for the continuous improvement on KPIs
0.34 - 0.67	Decision makers should be consider carefully whether it is worth to invest
0.68 – 1.00	Decision makers should invest into the information because high expectations support the continuous improvement process in respect to the stated objective.

2.4.3 Comparing information gain of on farm and slaughterhouse monitoring and inspection strategy

Three shells continuous improvement process model

The society claims an enormous usage of antibiotics in meat production. It is defined that the usage of antibiotics has to be reduced. Therefore, in the define phase the usage of antibiotics is the objective. In the measure phase, the quantity of antibiotics used per herd is calculated. The analysis phase displayed due to FMEA that the reason for the usage of antibiotics is the high proportion of pigs with respiratory distress detected during the meat inspection. The answers of the improve phase are diverse. The demand after more detailed information arises about the causing agents of the subclinical disease, respirators distress. An information source has to be investigated that enables to identify the pathogens continuously. Therefore, two control points were compared, inspection at slaughterhouse and on farm.

Score model to estimate the value of information for continuous improvement process

Both blood at slaughter and blood from living pigs enable a very high gain in time to derive the right decision. Both enable insight in the pathogen pressure (figure 2.4). Due to the fact that in the Southeast Bavarian pork value chain the laboratory results of blood from living pigs are not digitalized there is no information growth for the value chain actors. In contrast, laboratory results of blood sampled at slaughter are digitalized and can therefore be used as digitized data, descriptive information, comparative information, predictive information, prescribing information. Digitalized laboratory results are online available within one to five days and can be exchanged with permission within the entire pork value chain.

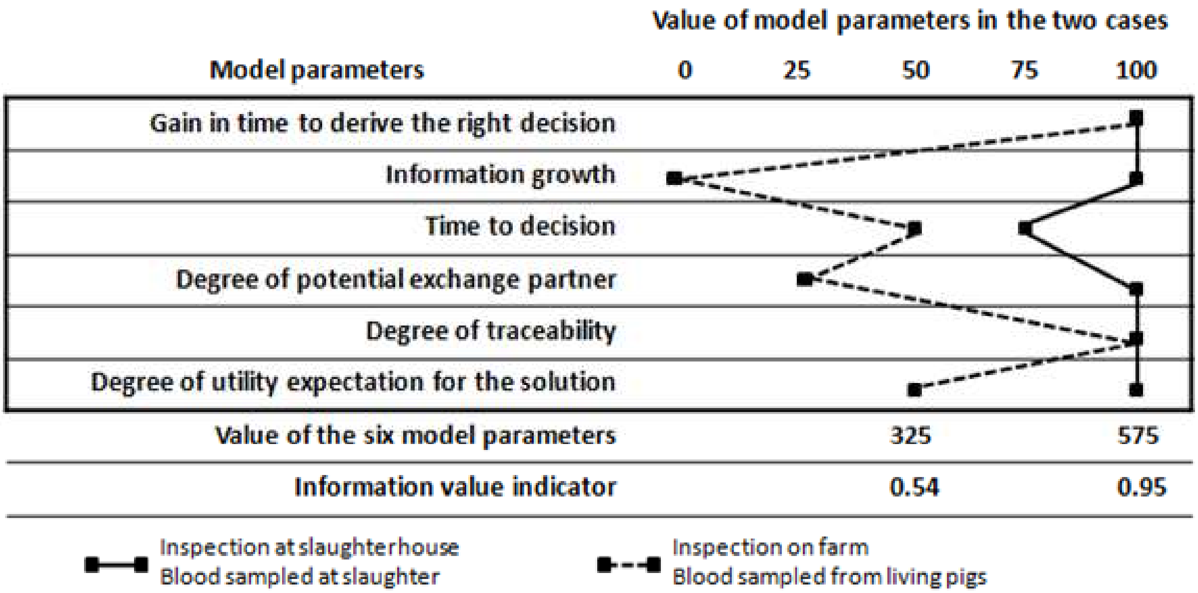

Figure 2.4 Comparison of two alternatives to receive insights into the pathogen pressure on farm to reduce the usage of antibiotics

Not digitalized information are available for the net-chain coordinator within seven to 14 days and are distributed within a small circle of chain actors. The traceability of the two information points, slaughterhouse or farm, is animal level. The degree of utility expectation for the solution to reduce the usage of antibiotics on chain level is higher for the inspection point slaughterhouse than for the farm level. The slaughterhouse is a bottleneck where nearly all pigs go through. A standardized approach is possible to reduce the usage of antibiotics and it is not an island solution as with blood samples on farm. As the information value indicator for inspection at slaughterhouse is above 0.68, in detail 0.95, the decision makers should invest into the information of blood sampled at slaughter because high expectations support the continuous improvement process in respect to the stated objective, reduction of antibiotic usage.

2.5 Discussion

The purpose of this chapter was to develop a decision support model to support the decision of the net-chain coordinator to gather valuable information on the continuous improvement process of KPIs. Therefore, a case study analysis on the pork value chain in Southeast Bavaria was conducted. The present pork value chain is in line with Brinkmann et al. (2011) and Trienekens et al. (2009) who describe a pork value chain as a chain of firm value chains that are mainly production stages. The existing information and knowledge management was derived, which shows that only a few information are still exchanged between a few actors and many information are still brain monopoly. This is contradicting the current opinion of chain actors.

In line with the used objective description in the define phase of the three shells continuous improvement model is Strotmann (1989). Strotman also determines these three economical objectives in the used socio-technical model. First, the overall goal is maximization contribution margin. A second goal is for example to maximize piglets or porkers traded within the pork value chain. That means maximization of piglets/sow/year and minimization of losses through animal diseases. Third, a minor goal is for example the minimization of fattening period. Adaption of the quality control chart to the circumstances in the red meat chain is possible. Here, a huge dataset is caused through carcass classification and organ classification. The variables are carcass weight, muscle meat share and salmonella status. The FMEA, used in the analysis phase was highlighted by Welz (1993) to assess the influence of animal diseases on the production process. The used information to execute FMEA are located on farm level. Petersen et al. (1989), Strotmann (1989), Verstegen et al. (1985) and Welz (1993) recommended to introduce a farm level decision support models. However, the complexity of pork chains is increasing and therefore it may be better to implement a decision support tool at the net-chain coordinator. This is supported through Schütz (2009).

To support the different phases of DMAIC cycle various tools are available. Gamweger et al. (2009) differentiated two groups of tools. On the one hand, team oriented problem solving methods, and on the other hand, statistical methods. The developed three shells continuous improvement model used a mix of those. In the define phase, team oriented problem solving methods are used, such as the House of Quality. In the others, statistical methods were used.

The score model to estimate the information value consists of six parameters. Ellebrecht (2008) used comparable to assess information and communication systems. Schütz (2009) applied the elements to rank service providers to their offered system functionalities. The present chapter turned out that the assessment elements can also be used to estimate the information value of different inspection points along the pork value chain.

As the three shells continuous improvement provess model is a young approach to evaluate information and knowledge it must be tested by other net-chain coordinators and in other industries. The practical application of the three shells continuous improvement model and the score model showed positive effects.

2.6 Conclusion

The formulated hypothesis, the value of information for monitoring and testing strategies to promote the continuous improvement process can be explained by the combination of quality tools, processes and tasks in a three shell continuous improvement process model, was accepted. The three shells continuous improvement process model enables a decision support for net-chain coordinators of pork value chains on which information to gather Based on the six criteria of the score model to estimate the information value, blood sampled at slaughter exceeds blood sampled on farm.

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Chapter 3 - Insights into key performance indicators of pork production through analyzing blood sampled at slaughter

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3.1 Abstract

The analysis of pig blood sampled at slaughter could be a practical tool to estimate pig herd health status on a regular basis and to determine the influence of pathogens on KPI. The objective of the present chapter was to explore the potential of slaughterhouse blood as predictor of pig herd health status, as reflected in technical performance of the herd and the usage of antimicrobial drugs. For this purpose, 20 pig herds located in Southeast Bavaria were enrolled. During four fattening periods, 30 blood samples at slaughter per farm were randomly collected and submitted for ELISA serology. The blood was tested for antibodies of five pathogens associated with the porcine respiratory disease complex (PRDC): *Mycoplasma hyopneumoniae* (Mhyo), *Actinobacillus pleuropneumoniae serotype 2* (APP 2), swine influenza virus (SIV), porcine reproductive and respiratory syndrome virus (PRRSV), and porcine circovirus type 2 (PCV2). Based on the ELISA serology results, a new developed serological indicator (SI) was calculated (the average proportion of positive samples).

Meaningful differences were found in serological statuses between the farms for the different pathogens. The multivariable linear regression analysis with a backward elimination procedure on the five pathogens indicated that PRRSV was the most influential pathogen affecting technical KPIs. APP2 mostly influenced the presence of pneumonia in pig herds and decreased the performance on KPI on pig health status. The new developed SI varied between zero and 1.00. The SI was significantly correlated with the KPI, percentage of pigs with symptoms of PRDC, the percentage of pigs with pneumonia per herd, the average daily growth rate (ADGR) and the average feed conversion rate (AFCR). The SI and the percentage of pigs with pneumonia per herd were good indicators for pig herd respiratory health status, as herds with a lower SI and a lower percentage of pneumonia used fewer antibiotics for respiratory disease.

The significant correlations between the serological results and the different KPIs indicates that the analysis of blood, sampled at slaughter, may aid to making better decisions on controlling consumer oriented quality production and pig herd health management. Monitoring the five pathogens from the PRDC may enable an increase in the KPIs. Blood sample at slaughter is valuable information source.

3.2 Introduction

The findings of chapter two, logically leads to the conclusion to investigate the information of blood sampled and analyzed at slaughter on the continuous improvement process on continuous improvement process of different KPIs along the pork value chain. Clinical and subclinical diseases are of major importance for the economic performance of pig herds. Beside intestinal problems, the porcine respiratory disease complex (PRDC) is the most challenging problem in intensive pork production systems (Fraile et al., 2010). The currently prevalence figures of lung lesions in slaughter pigs have more or less not changed in the last 20 years (Maes, 2013). PRDC results in high economic losses in modern pig production because of reduced growth rate, decreased feed conversion (Grest et al., 1997, Martinez et al., 2009, Martelli et al., 2009), increased costs of medication, and adverse effects on pig welfare (Sorensen et al., 2006). In addition, the usage of antibiotics to treat lung diseases is considered a downstream human health risk (Anderson, 2003).

Several viruses and bacteria, such as *Mycoplasma hyopneumoniae* (Mhyo), *Actinobacillus pleuropneumoniae serotype 2* (APP 2), swine influenza viruses (SIV), porcine reproductive and respiratory syndrome virus (PRRSV), and porcine circovirus type 2 (PCV2) are associated with PRDC (Sorensen et al., 2006, Wellenberg et al., 2010, Fablet et al., 2012). Subclinical courses of PRDC are frequently undiagnosed by farmers and veterinary practitioners (Martinez et al., 2009). The standard routine is the investigation of piglets on the presence of those pathogens, as executed by the Tiergesundheitsagentur (Czekala and Münster, 2013).

In addition, the development of clinical disease is influenced by a number of farm-specific factors such as farm management, biosecurity, and housing air quality (Mousing et al., 1990, Phillips et al., 2004).

Therefore, PRDC etiology is mainly farm specific and decision making based on clinical observations or lung pathology during meat inspection at the slaughterhouse alone is difficult. Thus, it is necessary to assess and to establish other diagnostic tools to determine the cause of disease or suboptimal performance in pig herds.

In Germany, the degree of pneumonia and pleurisy is assessed by the meat inspection, and by law, the results have to be communicated to the farmers. These results can be used to assess the lung health of the pig herds on the farm, but the results are non-specific. Farmers and their veterinarians could sample the pigs on the farm regularly, to assess the serological status of the herd, but this is costly. Collecting blood at slaughter is not routinely performed, mainly because the sampling would be too late exceeding the (crucial) time span live pigs may have been at risk from disease. Further, pigs at slaughter are rarely investigated on those pathogens associated with the PRDC, because of the higher organizational effort. However, blood sampled at slaughter is used for Salmonella monitoring or private monitoring on Mycobacterium avium.

Elbers (1991) concluded that the potential number of blood samples that can be collected at the slaughterhouse is high, collection can be performed rather easily, the collection costs are low, and farmers and their veterinarians can outsource the collection process. In this manner, blood sampled at slaughter could be a source for pig herd health monitoring and management systems (Meemken and Blaha, 2011). Previous studies have analyzed the link between lung pathology at slaughter and the causative agent of the lung disease and for that purpose sera collected at the slaughterhouse was used (Martinez et al., 2009, Fraile et al., 2010, Merialdi et al., 2011).

The present chapter is testing the second hypothesis: A monitoring and testing strategy, based on blood sampled at slaughter, is suitable for interpretation on key performance indicators.

3.3 Materials and methods

3.3.1 Farms and organization of data collection

Twenty herds in the Southeast of Bavaria, Germany, were selected for this study. The herds were selected according to the following three criteria: on year-round supply to the slaughterhouse participating in the study, heterogeneity in herd prevalence of pneumonia (the annual average prevalence of pneumonia in pigs at slaughter varied from 1.3% to 33.9%) and a member of one specific Bavarian grower association. During the farm visit farm characteristics were documented. The production system of 15 farms is finishing pigs and five produce pork in farrow-to-finish. The number of piglet origins per fattening period ranks between one up to nine. Farms change the piglet origin between the fattening periods others stable the same piglet origin. The distance between the farms varies between below 0.5 km up to 3 km. The stable size ranks between 550 and 3,500. The youngest building was four years old and the oldest 36 years. The farms used as well AIAO or continuous load per department. Cleaning of the department was done infrequently between the farms. The majority cleaned after each fattening periods (3-4 times per year) or only once or twice per year. Seven out of the 20 farms did not disinfect the departments. All farms have QS status one and only one has Salmonella status two. Data to characterize the pilot herds are summarized in table 3.1.

Table 3.1 Characteristics of 20 pilot farms

Criteria	Level	No. herds
Production system	Finishing piglets from 30kg	15
	Farrow to finish	5
Annual number of piglet herd origin	1	4
	2	3
	≥3	8
	Own production	5
Changing piglet origins	Yes	8
	No	7
Distance to next farm	≤ 0.5 km	10
	0.5 – 1 km	7
	1.2 – 2 km	2
	2.1 – 3 km	1
Fattening places	≤1000 places	7
	1001 – 1500 places	11
	>1500 places	2
Building age	0 – 10 years	6
	11 – 20 years	5
	21 – 30 years	4
	31 – 40 years	5
Stable management	All in all out per department	16
	Continuous load per department	4
Vaccination piglets	APP2	0
	PCV-2	2
	Mhyo + PCV2	15
	Mhyo + PCV2 + PRRSV	3
QS Status	One	20
Salmonella status	One	19
	Two	1

Different data collection points were used. Data collection on the clinic was done in the first out of four investigated fattening periods and supported by employees of the Bavarian Animal Health Service, and an agricultural scientist from the grower organization performed one clinical observation per herd. The farm visit was scheduled for two hours. The examination of the fattening pigs was performed between one and 20 days prior to slaughter. The percentage of pigs with symptoms of PRDC was assessed based on the observed symptoms. The symptoms included coughing, paleness, respiratory distress and pigs with a weight 20% lower than the estimated average weight of the batch in the compartment.

Data collection of the pathological lung lesions was supported by official meat inspection personnel, who performed assessment during routine post-mortem meat inspection. At this slaughterhouse, the following lesions were documented: percentage of pigs with middle-grade pneumonia (10 – 30% surface affected) and percentage of pigs with high-grade pneumonia (>30%). In the analysis, the total percentage of pigs with pneumonia per herd was used, without differentiating between middle-grade and high-grade. Pleurisy was recorded insufficiently at the time of the investigation. The farms submitted the performance on ADGR and AFCR as well as the usage of antibiotics through a small questionnaire (table 3.2).

Table 3.2 Criteria, data collection point, responsibility and proceeding

Criteria	Period	Data collection point	Responsibility	Proceeding
Usage of antibiotics	one	Farm level	Farmer and his/her veterinarian	Usage of antibiotics for PRDC Yes or No
Percentage of pigs with symptoms of PRDC	one	Farm level	employees of the Bavarian Animal Health Service and an agricultural scientist	Percentage of pigs with symptoms. The symptoms included coughing, paleness, respiratory distress and pigs with a weight 20% lower than the estimated average weight of the batch in the compartment
Percentage of pigs with pneumonia	one, two, three, four	Slaughter-house	official meat inspection personnel	Percentage of pigs with middle-grade pneumonia (10 – 30% surface affected) and percentage of pigs with high-grade pneumonia (>30%)
ADGR (g)	one, two, three, four	Farm level	15 out of 20 herds by the Federal Bavarian consultancy (LKV Bayern) others applied same) schema	Gram per day
AFCR (kg/kg)	one, two, three, four	Farm level	15 out of 20 herds by the Federal Bavarian consultancy (LKV Bayern) others applied same schema	One kilo growth to consumed feed in kilo

PRDC = Porcine respiratory disease complex, ADGR = Average Daily Growth Rate, AFCR = Average Feed Conversion Rate LKV = Landeskuratorium der Erzeugerringe für tierische Veredelung in Bayern e.V.

3.3.2 Collection and analysis of blood samples

In total 587 randomly collected blood samples were available of pigs out of four fattening periods. From the first fattening period 15 samples were collected. Of period two, three and four five samples were randomly collected. Deliveries were selected randomly. The blood samples were collected after scalding and dehairing from the stick hole for debleeding. The scalding system at the slaughterhouse is an open condensation system. Every time, the same person performed random sampling. The blood was directly filled in the tube which was send to the laboratory within 24 hours. Here the serum was obtained by centrifugation for 5 minutes at 3500 rpm and 4 °C (Heraeus, Megafuge 1.0 R). The serum was stored at -20 °C until testing. Sera were tested for PRRSV antibodies , APP 2 antibodies, PCV2 antibodies, SIV antibodies, Mhyo antibodies (table 3.3). The tests were performed according to the user manuals of the respective test kits. Scoring samples as positive relied on the following cut-offs presented in user manuals: PRRS S/P $\geq$ 0.40, PCV2 S/P $\geq$ 0.454, SIV S/P $\geq$ 0.40, Mhyo S/P $\geq$ 0.30 and APP 2 S/P $\geq$ 0.30.

Table 3.3 Used test kits for analysis of serum samples

Pathogen	Cut offs	Test Kit	Producer
PRRSV	0.40	ELISA HERDCHECK PRRS X3 kit	IDEXX Laboratory, IDEXX Switzerland AG, Switzerland
PCV2	0.454	ELISA INGEZIM Circo IgG kit	Inmunologia Y Genetica Aplicada, Spain
SIV	0.40	ELISA IDEXX HerdCheck H1N1 kit	IDEXX Laboratory, One IDEXX Drive, USA
Mhyo	0.30	ELISA IDEXX HerdCheck kit	IDEXX Laboratory, One IDEXX Drive, USA
APP 2	0.30	ELISA ID Screen APP2 Indirect kit	IDVET, Montpellier, France

PRRSV = porcine reproductive and respiratory syndrome virus; PCV2 = porcine circovirus type 2; SIV = swine influenza viruses; Mhyo = *Mycoplasma hyopneumoniae*; APP 2 = *Actinobacillus pleuropneumoniae serotype 2;*

3.3.3 Performance indicators and statistical methods

To describe the overall sera reactivity per herd by one value, the SI was developed. SI was calculated by the following formula, whereby P is the rate (%) of seropositive samples per pathogen of the randomly taken samples. The sum of the Ps is divided by 500. 500 is the maximum that can be reached when all samples were positive for all five analyzed pathogens. The SI ranges between 0 and 1. A SI of one indicates a high pathogen pressure and zero absence of enzootic risk.

$$\text{Serological indicator} = (P_{PRRSV} + P_{PCV2} + P_{Mhyo} + P_{SIV} + P_{APP2})/500$$

ADGR and AFCR were used to assess the technical herd performance. AFCR and ADGR were assessed in 15 out of 20 herds by the Federal Bavarian consultancy (LKV Bayern), as it is routine on these farms. The usage of antimicrobial drugs was documented only for the project purpose with respect to respiratory diseases and the application per herd was coded as Yes or No, including injection as well as oral application. The farmers provided the results on a pre-defined questionnaire after the fattening period.

For the statistical analysis the statistical package SPSS 20 (IBM SPSS 20) was used. ANOVA, linear regression and multivariable linear regression analysis with a backward elimination procedure were conducted. For the multi-regression models, Durbin-Watson statistics were applied to test the assumption of independent errors. Values close to two indicated that the assumption of independent errors were tenably. A stepwise backward exclusion of predictor variables in a multi-regression model was run to determine the most influential factors. Briefly, first, all predictor variables were entered into the model. The weakest predictor variable ($p > .05$) was removed and the regression re-calculated. If this significantly weakened the model, the predictor variable was re-entered. Otherwise, it was deleted. This procedure was repeated until only the significant predictor variables and predictors, that were part of a significant interaction effect, remained in the model (Crawley, 2002). A one-Way ANOVA was applied to assess the differences in the mean between the two groups of farms with and without usage of antimicrobial drugs. To assess the variables influencing the value of the serological indicator a Chi-quadrate Pearson test was applied.

3.4 Results

3.4.1 Variation of key performance indicators and serological profile

The KPIs were different between the 20 investigated farms. The percentage of pigs with pneumonia per herd decreased from 11.1% in the first tested fattening period to 8.8% in the fourth tested period (table 3.4). The average size of delivery was stable over the four periods. The mean of the AFCR was in fattening period one 2.9 kilo per one kilo growth and in the other periods 2.8. The mean of the ADGR was stable and varied between 767g and 785g. Consequently, the herd data did not change heavily between the four fattening periods. The mean of the SI varied between the four investigated periods between 0.46 and 0.51 with a constant standard deviation of minimum 0.21 and maximum 0.26 (table 3.4). It could not be confirmed that the SI increased between summer and winter period. Fattening periods three and four can be assessed as winter periods.

Table 3.4 Variation of key performance indicators

Variable	Fattening period	Mean	SD	Min	Max
Percentage of pigs with pneumonia per herd	1	11.1 %	7.5	0.8	25.6
	2	11.9 %	10.5	0	39.1
	3	9.4 %	9.1	0	30.1
	4	8.8 %	9.0	0	32.1
Average Daily Growth Rate	1	767g	55g	637g	913g
	2	774g	61g	699g	944g
	3	785g	55g	690g	928g
	4	773g	63g	625g	895g
Average Feed Conversion Rate	1	2.9	0.2	2.62	3.32
	2	2.8	0.1	2.56	2.95
	3	2.8	0.1	2.52	3.06
	4	2.8	0.1	2.63	3.12
Serological Indicator	1	0.47	0.26	0	0.85
	2	0.51	0.21	0	0.88
	3	0.49	0.23	0	0.88
	4	0.46	0.23	0	1.00

SD = Standard deviation, Min = Minimum, Max = Maximum

Concerning the serological herd profile, the mean of % seropositive pigs per herd varied between the four fattening periods for PRRSV between 74% and 85%, PCV2 between 40% and 53%, between SIV 19% and 38%, Mhyo between 51% and 72%, APP 2 between 17% and

24%. Minimum and maximum was for each parameter and every period zero and 100. Only in the first period, the maximum of % seropositive pigs was for SIV 87% (table 3.5).

Table 3.5 Variation of % seropositive results of blood analysis

Parameter	Fattening period	Mean	SD	Min	Max
PRRSV	1	74 %	40	0	100
	2	82 %	37	0	100
	3	81 %	36	0	100
	4	85 %	37	0	100
PCV2	1	53 %	34	0	100
	2	43 %	35	0	100
	3	52 %	33	0	100
	4	40 %	34	0	100
SIV	1	19 %	25	0	87
	2	38 %	35	0	100
	3	30 %	29	0	100
	4	22 %	29	0	100
Mhyo	1	62 %	39	0	100
	2	72 %	36	0	100
	3	51 %	44	0	100
	4	53 %	45	0	100
APP 2	1	24 %	37	0	100
	2	21 %	39	0	100
	3	20 %	35	0	100
	4	17 %	35	0	100

SD = Standard deviation, Min = Minimum, Max = Maximum
PRRSV = porcine reproductive and respiratory syndrome virus, PCV2 = porcine circovirus type 2, SIV = swine influenza viruses, Mhyo = *Mycoplasma hyopneumoniae*, APP2 = *Actinobacillus pleuropneumoniae serotype 2*

Based on the results of the 78 fattening periods, the quartiles were calculated for ADGR, AFCR, percentage of pigs with pneumonia, and SI. The median for ADGR is 773g, 2.86 for AFCR, 7.66 % for pigs with pneumonia per herd and 0.49 points for the SI (table 3.6). The values of ADGR and AFCR are close to results of the Federal Bavarian consultancy (LKV Bayern 2011). Therefore, the quartiles can be classified as valid and representative. For the quartiles of percentage of pigs with pneumonia and SI no references exists. Therefore, it was decided to calculate the ADGR and AFCR based on the present herds and not to use the LKV quartiles. Furthermore, the quartiles were calculated based on the four investigated fattening periods. This is the same approach as used by the LKV Bayern for ADGR and AFCR.

Table 3.6 Quartiles of key performance indicators

	ADGR	AFCR	% of pigs with pneumonia	Serological indicator
Third quartile	802	2.92	16.21	0.64
Median	773	2.86	7.66	0.49
First quartile	736	2.71	4.24	0.32

ADGR = Average daily growth rate, AFCR = Average feed conversion rate

3.4.2 Serological indicator in relation to other key performance indicators

In four out four fattening periods was the SI was significant correlated with percentage of pigs with pneumonia per herd (table 3.7). The percentage of pigs with pneumonia increased when the SI increased. The R-square varied between 0.29 and 0.72. The correlation coefficient varied between 0.54 and 0.85.

In two out of four fattening periods the SI was significant correlated with ADGR (table 3.7). The ADGR was decreasing with an increasing SI. The R-square varied between 0.24 and 0.44. The correlation coefficient varied between -.49 and -.67.

In two out of four fattening periods the SI was significant correlated with AFCR (table 3.7). The AFCR was getting worse with an increasing SI. The R-square varied between 0.28 and 0.30. The correlation coefficient varied between 0.53 and 0.54. The graphical presentation of the relationships can be found in the appendix, figure A.1 to A.12.

Table 3.7 Serological indicator and the KPIs, percentage of pigs with pneumonia, ADGR and AFCR

KPI	Fattening period	R-square	Correlation coefficient[1]	p-value	n
SI and percentage of pigs with pneumonia	1	.722	.850	<.0001***	20
	2	.405	.636	.003**	20
	3	.293	.541	.017*	19
	4	.438	.662	.002**	19
SI and ADGR	1	.239	-.489	.029*	20
	2	.443	-.665	.001**	20
	3	.193	-.439	.060	19
	4	.033	-.181	.459	19
SI and AFCR	1	.295	.543	.013*	20
	2	.281	.530	.024*	18
	3	.071	.267	.318	16
	4	.159	.398	.141	15

[1] Pearson correlation coefficient two-tailed, *P < .05 **P < .01 ***P < .001
KPI = Key performance indicator, SI = Serological indicator, ADGR = Average daily growth rate, AFCR = Average conversion rate

Based on multivariable linear regression analysis with a backward elimination procedure, APP2 was responsible for an increase in percentage of pigs with pneumonia per herd in four out of four fattening periods (table 3.8). If all samples were positive for APP2 then the percentage of pigs with pneumonia increased by 5.4% points (period one), 20.8 % points (period two), 20.1 % points (period three) and 10.5 % points (period four). These were the highest impact factors, only PCV2 had a higher influence in the first period, but not in other periods. The second most determined pathogen was SIV, with an increase by 100% positive samples of 7.8 % points (period one), 12.0 % points (period three) and 13.5 % points (period four).

Table 3.8 Significant relations between the KPI, percentage of pigs with pneumonia, and prevalence of pathogens in the backward multi-variable linear regression analysis, regression parameters (ß), standard error of regression parameters (SE (ß)), P values, Durbin-Watson values and R^2

Period	Dependent variable	Con-stant	Significant independent variable	ß ± SE (ß)	p-value	Durbin Watson	R^2
1	Percentage of pigs with pneumonia	-.110	PCV2 SIV APP 2	.158 (.027) .078 (.032) .054 (.025)	≤ .0001 .024 .044	1.912	.818
2	Percentage of pigs with pneumonia	1.249	Mhyo APP 2	.088 (.040) .208 (.036)	.041 ≤ .0001	1.897	.688
3	Percentage of pigs with pneumonia	5.269	PCV2 SIV APP 2	-.071 (.040) .120 (.042) .201 (.034)	.096 .011 ≤.0001	2.814	.756
4	Percentage of pigs with pneumonia	3.772	SIV APP2	.135 (.060) .105 (.050)	.039 .051	2.520	.535

PRRSV = porcine reproductive and respiratory syndrome virus, PCV2 = porcine circovirus type 2, SIV = swine influenza viruses, Mhyo = *Mycoplasma hyopneumoniae*, APP2 = *Actinobacillus pleuropneumoniae serotype 2*

Concerning the influential pathogens influencing mostly the ADGR, the multivariable linear regression analysis with a backward elimination procedure displayed, that PRRSV was in the first and second fattening period the most influential pathogen (table 3.9). If all samples were tested positively on PRRSV then the ADGR decreased by 72.9 g. In the second period, the decrease was 133g. PCV2 decreased in the third period the ADGR by 79.1 g. For the fourth period none valid model could be derived.

Table 3.9 Significant relationships between the KPI, ADGR, and prevalence of pathogens in the backward multi-variable linear regression analysis, regression parameters (ß), standard error of regression parameters (SE (ß)), P values, Durbin-Watson values and R^2

Period	Dependent variable	Constant	Significant independent variable	ß ± SE (ß)	P value	Durbin Watson	R^2
1	ADGR	820.45	PRRSV	-.727 (.277)	.017	1.207	.277
2	ADGR	883.89	PRRSV	-1.33 (.232)	< .0001	1.539	.646
3	ADGR	828.12	PCV2	-.791 (.383)	.055	1.765	.200
4	ADGR	773.00	-	-	-	-	-

PRRSV = porcine reproductive and respiratory syndrome virus, PCV2 = porcine circovirus type 2, SIV = swine influenza viruses, Mhyo = *Mycoplasma hyopneumoniae*, APP2 = *Actinobacillus pleuropneumoniae serotype 2*

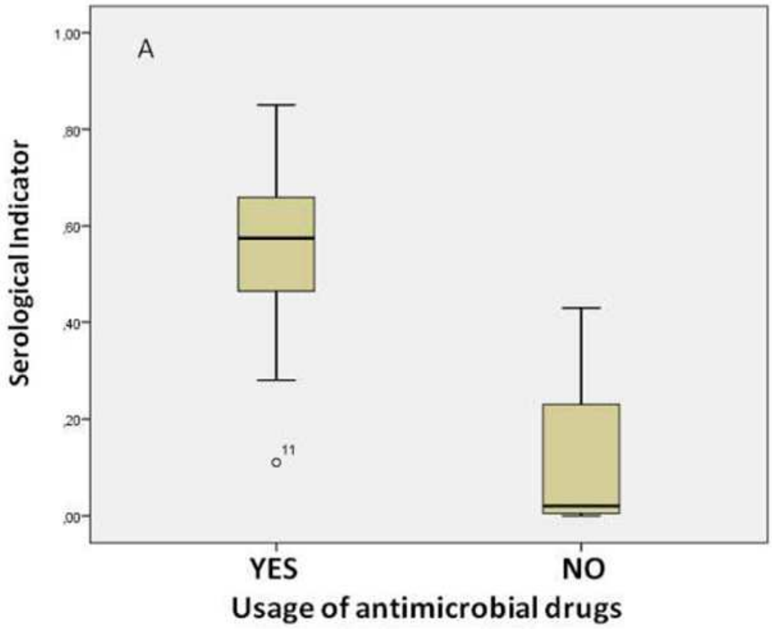
PRRSV turned out to be the most influential pathogen on AFCR in the first and second period (table 3.10). The AFCR was multiplied with 1000 to calculate with gram instead of kilo. This leads to more detailed results. If all samples were positive for PRRSV then 217 g and 176 g more of feed were used to produce one kg of growth. In period three, APP2 was responsible an increase of 164 g, and in period four, PCV2 was responsible for an increase of 233 g.

Table 3.10 Significant relationships between the KPI, AFCR, and prevalence of pathogens in the backward multi-variable linear regression analysis, regression parameters (ß), standard error of regression parameters (SE (ß)), P values, Durbin-Watson values and R^2

Period	Dependent variable	Constant	Significant independent variable	ß ± SE (ß)	P value	Durbin Watson	R^2
1	AFCR	2747.45	PRRSV	2.168 (.731)	.008	1.625	.328
2	AFCR	2667.58	PRRSV	1.758 (.651)	.016	1.199	.313
3	AFCR	2777.51	APP 2	1.638 (.927)	.099	2.130	.182
4	AFCR	2705.01	PCV 2	2.325 (.811)	.013	2.136	.387

PRRSV = porcine reproductive and respiratory syndrome virus, PCV2 = porcine circovirus type 2, SIV = swine influenza viruses, Mhyo = *Mycoplasma hyopneumoniae*, APP2 = *Actinobacillus pleuropneumoniae serotype 2*

Concerning the usage of antimicrobial drugs, there are significant differences between the farms that used antimicrobial drugs and those that did not for the SI (p-value .002) and the percentage of pneumonia per herd (p-value .009) (figure 3.1 and see details in appendix table A.1). In addition, herds with less than five percent of pigs with pneumonia per herd used no antimicrobial drugs.



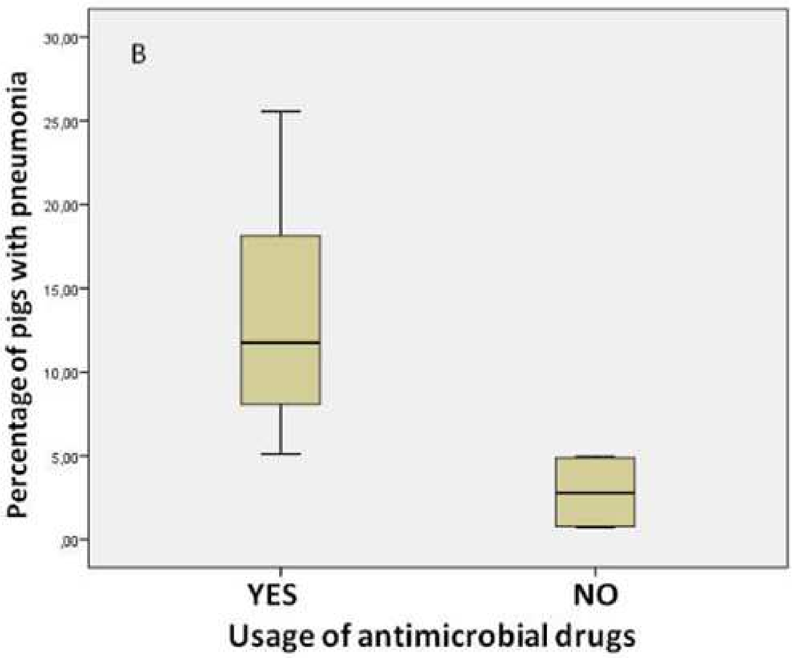


Figure 3.1 Serological indicator value and the percentage of pigs with pneumonia per herd for herds with using (A) and not using antimicrobial drugs (B)

Further, the SI was significant correlated with the clinical symptoms typical for PRDC which was investigated in the first fattening period (table 3.11). The correlation coefficient was .80 and R-square was .17. The symptoms of clinical disease were significantly higher on farms with a high seroprevalence of APP2 (table 3.12).

Table 3.11 Correlation coefficients between serological indicator and % of pigs with symptoms

	Percentage of pigs with symptoms of PRDC
R-square	.168
Correlation coefficient	.797[1]
p-value	<.0001

[1]Spearman correlation coefficient

Table 3.12 Significant relationships in the backward multi-variable linear regression analysis, regression parameters (ß), standard error of regression parameters (SE (ß)), P values and Durbin-Watson values

Dependent variable	Constant	Significant independent variable	ß $\pm$ SE (ß)	P value	Durbin Watson	R^2
Percentage of pigs with symptoms of PRDC	2.224	APP2	.182 (.060)	.007	2.115	.337

3.4.3 Variables influencing the value of serological indicator

To assess the variables influencing the value of the serological indicator a Chi-quadrate Pearson test was applied. The tested variables were divided into two groups. The SI as well, group one SI $\leq$ 32 and group two SI > 32. Further, all fattening periods were investigated at once, in sum 78 periods of 20 herds over four fattening periods. Two fattening periods could not be investigated. Significant differences appeared between the fattening periods with a very low serological indicator (<.32) and serological indicator higher than .32 through the department assignment process All-in-all-out or continuous. The amount of piglet origins per year significantly influences the SI value. Distance between farms has an influence on the serological indicator as well as the building age (table 3.13). However, production system and whether the farm changes the piglet origins are not significantly influencing the value of the SI.

Table 3.13 Fix and variable factors influencing the value of the serological indicator

	Group 1	Group 2	Chi-quadrate Pearson	Alpha
Production system	Finishing pigs (n = 58)	Farrow to finish (n = 20)	.006	.939
Department assignment process	All-in-all-out (n = 62)	Continuous (n = 16)	3.97	.046*
Amount of piglet origin per year****	≤ 2 (n = 40)	≥ 3 (n = 18)	9.105	.003**
Distance between farms	< 1 kilometer (n = 66)	≥ 1 kilometer (n = 12)	18.12	<.0001***
Changing piglet origins****	Yes (n = 30)	No (n = 28)	2.74	.098
Building age	≤ 10 year (n = 24)	> 10 years (n = 54)	14.80	<.0001 ***

*P < .05 **P < .01 ***P < .001 **** farrow-to-finish farms excluded

3.4.4 Enzootic risk matrix

When grouping the 78 fattening periods of the 20 pig farms according to their enzootic risk potential, four groups could be identified. For setting the boundaries the result of the quartile calculation was used (figure 3.2). The 25^{th} percentile of the SI is 0.32 and of percentage of pigs with pneumonia 4.24. Group one, absence of high enzootic risk, had less than 4.24 percentages of pigs with pneumonia and the blood samples at slaughter were only positive for a few pathogens, mainly PRRSV or PCV2. Group two, controlled high enzootic risk, could reach through the right measures that the pathogen pressure was not influencing the respiratory health. In those herds blood was tested positive for all five pathogens. Group three, uncontrolled high enzootic risk, showed a high pathogen pressure and worse respirator system health. Maybe the farmers took the wrong measure or were not aware of respiratory distress of their pigs. Only a few fattening periods, were assigned to group four, less pathogen pressure and higher respiratory problems. In this group other factors, such as climate change or damage of the air ventilation, could lead to a worst respiratory system health.

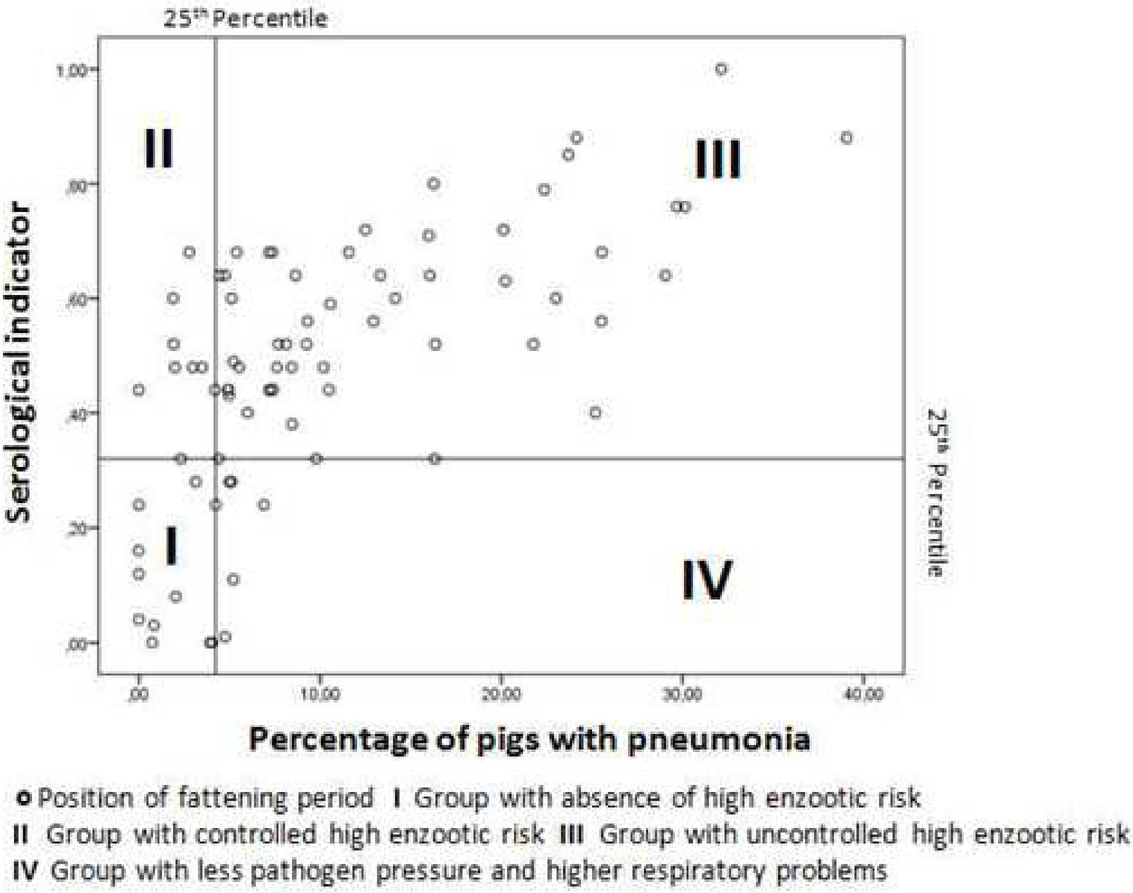


Figure 3.2 Enzootic risk matrix

3.5 Discussion

The analysis of 587 slaughterhouse blood samples of 20 herds over four fattening periods showed four times significant correlations between the SI and percentage of pneumonia per herd, three time between SI and technical herd performance. Pigs were selected at random to ensure that the slaughterhouse blood sampling was fully representative for the herd. The herds included in this study were not selected at random from the entire population of Southeast Bavarian herds and, therefore, may not be representative of this population as a whole. Nevertheless, the herds had characteristics that made them comparable to other pig farms.

Instead of analyzing the percentage of pigs with middle- and high-grade pneumonia separately, the findings were summarized as the percentage of pigs with pneumonia as determined by the meat inspection. The cut-off for recording pneumonia at the slaughterhouse was set to 10% of the lung surface by the official authorities. Because of this, some information were lost because the herds with no pneumonia could have had pneumonia, just with less than ten percent affected lung surface. Bias also arose because the assessment of the lungs was executed by different federal veterinarians, as determined by who was on duty at the time of the assessment.

The interpretation of the presented regression models should be conducted carefully because of the presence of multicollinearity. For models 1 and 2, the Durbin-Watson value was close to 2, which means that the residuals are uncorrelated. All four models did not produce values below 1 or greater than 3. That should promote awareness. Nevertheless, the interpretation should be performed carefully because PRRSV was significantly correlated with PCV2 (correlation coefficient .649) and Mhyo (.768). PCV2 was significantly correlated with Mhyo (.673) and APP 2 (.444). As there is no perfect correlation, it may not be assumed that the PRRSV in models 3 or 4 can be directly substituted with another pathogen.

An extra complication in the analysis of the results is that the ELISA tests do not differentiate between antibodies from natural infection or vaccination. It was concluded, in accordance with Sibila et al. (2009) and Fraile et al. (2010), that the detected antibodies against Mhyo were the result of natural infection. In the present study, 18 out 20 herds were vaccinated against Mhyo. However, two vaccinated herds were seronegative for Mhyo antibodies. In addition, all herds were vaccinated against PCV2. Nevertheless, one herd was seronegative for PCV2 antibodies. Moreover, there was clearly variability between farms concerning the same vaccination status. Therefore, it can be concluded that the serological response seen at slaughter would be due to infection during the fattening period.

Concerning the assessment of the symptoms associated with PRDC, it needs to be considered that the farm visit was performed between one day and 20 days prior to slaughter. Consequently, infections that have occurred far before slaughter were not seen, in the beginning of the fattening period. Therefore, the clinical assessment should be understood as a biased representation of the disease history. The time point of the farm visit close to the slaughter should be considered carefully too, as respiratory diseases mostly occur in the flat deck or the beginning of the fattening period.

The present study examined, how serology at slaughter can be used to steer herd health management . Elbers (1991), more than 20 years ago, studied the differences in serological profiles between farms based on analyzing blood sampled at slaughter. It is useful to compare the present study with Elbers (1991) and other recent studies that have used blood sampled at slaughter as an information source, such as Martinez et al. (2009), Fraile et al. (2010) and Merialdi et al. (2011). These authors looked at the causes of lung pathology at slaughter and examined serology at slaughter to elucidate the pathogens causing the deviations. All four studies correlated the pathological lung lesions with their tested parameters. The included parameters varied between the studies. None of the other studies included PCV2, whereas ADV was not included in the present study because of the current official ADV-free status of Germany. Our study confirmed that the more recently identified PCV2 influences the percentage of pneumonia significantly, which confirms PCV2 as an important co-factor associated with recent cases of PRDC (Kim et al., 2003, Dorr et al., 2007, Wellenberg et al., 2010). Additionally, the lung lesion recording method varied slightly between the studies. As in this study, Elbers (1991) used the percentage of pigs with pneumonia. Martinez et al. (2009) used a mean lesion value based on catarrhal-purulent bronchopneumonia, pleuropneumoniae and pleuritis. None of the studies used the results of the federal post-mortem meat inspection. All three studies confirmed that lung infections influence technical performance, but that the pathogen and size of the effect differ from study to study, which is reasonable given the multi-factorial nature of the disease complex.

In the present chapter, multivariable linear regression analysis with a backward elimination procedure indicated that PRRSV was most strongly associated with ADGR and AFCR. With respect to the ADGR, Elbers (1991) found a significantly higher growth in herds negative for SIV (H1N1, H3N2) and ADV. Martinez found no significant association between ADGR with Mhyo and ADV. Mhyo and SIV (H1N1) demonstrated no influence on the ADGR in the present study. With respect to AFCR, Martinez et al. (2009) observed that Mhyo and ADV were negatively associated. In the present chappter, this association was not found. The comparable studies found different pathogens causing increases in pneumonia, decreases in ADGR or increases in AFCR because different pathogens were involved in the analysis. None of the studies investigated the same five pathogens as the present study.

Elbers (1991) included the usage of veterinary drugs in his research objective and found no significant association with the degree of seropositivity, whereas in the present study, a significant correlation between the serological indicator and the usage of antimicrobial drugs was observed.

Elbers (1991) also investigated clinical signs, but in contrast to the present study, no significant association between the percentage of pigs with symptoms of PRDC and APP2 was observed. Elbers (1991) did not find any association between the degree of seropositivity and clinical signs.

The differences between the studies underlines that serology at slaughter provides a great amount of information about the various reasons for lower technical performance in pig herds, but that at farm level, the serological details need to be associated with other environmental factors to deduce the causal complex.

It might be useful to know the pathogens circulating on a particular farm to improve the health of pigs. The serology of blood collected at the time of slaughter can be used for this purpose. As circumstances on a farm can continuously change, such as origin of the piglets, it may be useful to continuously monitor the endemic situation. As this serological sampling in live pigs may be expensive, the slaughterhouse may be a cost-effective alternative. The present study indicated that the slaughterhouse is a useful point to collect data on the herd health status as meaningful differences between farms were observed, and significant correlations were found with regard to important parameters and causative agents. Through analyzing blood sampled at slaughter, decision makers at the farm can work on improving the known weak points. Knowing the herd-specific pathogens causing respiratory health system problems may enable the development of structured quality management measures to reduce their influence on herd management. The establishment of a benchmark system may enable the promotion of farms to work actively on pathogen control. Lastly, controlling herd-specific pathogens may allow for a reduction in the amount of antibiotics used in pig herds.

The developed four square enzootic risk matrix enables a grouping of farms. However, application should be done carefully. The classification of the groups bases on the 20 pilot herds and may be different in reality. Further, the enzootic risk is only concerned with the PRDC.

3.6 Conclusion

The formulated hypothesis, a monitoring and testing strategy based on blood sampled at slaughter is suitable for interpretation on key performance indicators, was accepted. Blood sampled at slaughter explained clinical observations at the farm level, indicated the causative pathogens of PRDC and the resulting pneumonia during meat inspection, and explained poorer technical performance and the use of antimicrobials for PRDC. Therefore, the serology of blood sampled at slaughter is a valid information source for assessing pig herd health status. The use of the slaughterhouse as control point for pig herd health status is recommended. The SI should be assessed as new KPI for benchmark of fattening periods as well as organizational benchmark of farms. It might be beneficial for the pork supply chain to work with this information source to make safer decisions regarding vaccinations, piglet sourcing and usage of antibiotics. This may lead to improve the health and welfare of pigs.

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Chapter 4 - Conformity and non-conformity costs of pig herd health status

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4.1 Abstract

A million € figure of financial losses is impressive at the national level to prevent and contain production diseases. However, it is not guarantee that sufficient incentives exists for the farmer to adapt control strategies for production diseases if made available. Further, an economic analysis of production diseases is mainly done to assess the costs and benefits to the society. Even more relevant is the financial analysis. It takes costs and revenues into account that are only relevant for the farmer. The objective of the present chapter is to assess the financial impact, the non-conformity costs, of porcine respiratory disease complex (PRDC) on 20 German fattening farms. The information was gained through blood sampled at slaughter and summarized in the serological indicator (SI), which was used to assess the financial influence level and to determine the most financial relevant pathogens associated with PRDC. For the calculation, primary data of four fattening periods and two scenarios were applied to estimate the lower and upper limit. Further, the break even of a monitoring service was calculated for two options based on the results of blood sampled at slaughter.

The gross margin per stable place varies between 17.90 € and 119.51 €. The SI and the gross margin per stable place are significant correlated in the first fattening period -.584 ($p < .01$) and the second fattening period -.656 ($p < .01$). A SI of one halved the gross margin per stable place in both scenarios. PRRSV was in two out for fattening periods the most relevant pathogen on the gross margin per stable place.

The break even of the monitoring service and prevention costs such as vaccination of piglets is minimum 115 and maximum 766 bought piglets per year. Break even in ordering highly qualitative piglets is minimum 77 and maximum 230 bought piglets per year.

4.2 Introduction

The findings of chapter three promoted the interest to analyze the financial impact of production diseases and so to assess the monetary incentives to use a monitoring service of pathogens associated with the PRDC. The economic performance of pig herds is influenced by different production aspects such as the composite of feed, the animal density and genetic (Lattore et al., 2008, Wang et al., 2008). Subclinical and clinical gastrointestinal and respiratory diseases influence the performance (Fraile et al., 2010). Subclinical courses of the PRDC are frequently undiagnosed by farmers and veterinary practitioners (Martinez et al., 2009).

Blood at slaughter is an efficient control point to predict the herd health status on the PRDC (Elbers, 1991, Düsseldorf et al., 2012). The SI is a predictor variable and new KPI for respiratory health and can be used as well as performance benchmark (Düsseldorf et al., 2012). The SI increases with the increase in the key performance indicators, percentage of pigs with symptoms of PRDC and percentage of pigs with pneumonia per herd. Consequently, an increase in the value of the SI leads to the conclusion that the herd faced respiratory distress during the production cycle.

Failure in production such as production diseases cause, as in other industries, cost of conformance and non-conformance. The costs of non-conformance, specifically, the failure costs are high in the pork value chains (Stewart, 2001). The economic impact of one pathogen, for example PRRSV, is high. The occurrence decreases the reproduction rate in breeding herds, increases the mortality rate and leads to inefficient technical herd performance. Each year this pathogen causes $ 560.32 million losses to US swine producers. The PRDC results in high economic losses in the modern pig production, because of reduced growth rate and decreased feed-conversion (Grest et al., 1997, Martinez et al., 2009, Martelli et al., 2009), increased costs of medication and adverse effect on pig welfare (Sorensen et al., 2006). Ascaris suum caused incurred economic losses as condemnation of livers at slaughter, decreased daily gain and feed conversion efficiency and cost of anthelmintic treatment (Boes et al., 2010). Stewart (2001) estimated the loss of US $ 17.5 million due to liver condemnation and loss of US $ 60.1 million for extra feed to terminate pigs at slaughter.

It is useful to figure the economic impact of production diseases on farm level in order to promote farms to improve the pig herd health status. While an aggregate of million € figure is impressive at the national level, it is not guarantee that sufficient incentives exists for the farmer to adapt control strategies for production diseases if made available. A national estimation of the total losses does not gain anything nor contribute effectively to the decision making (Perry et al., 1999).

The aim of the present chapter is to assess the non-conformance costs of PRDC on farm level. Hereby, incentives to farms to improve the respiratory system health status of the farm should be derived. Therefore, the gross margins of four fattening periods of 20 pig farms are compared with the SI which indicates the pig herd status on PRDC. To adapt control strategies for PRDC by farms the appraisal costs of an innovative monitoring strategy are compared with prevention costs.

Further, the present chapter is testing the third hypothesis: The monitoring and testing strategy enables to explain the financial impact of production diseases on farm level and that the benefits of this strategy outweigh the costs.

4.3 Material and methods

4.3.1 Categories of operative quality, appraisal and prevention costs

DIN ISO 9004-1 classifies operative quality costs as costs of conformance (costs of control) and costs of non-conformance (costs of failure of control). The main objective of quality costs reporting is to provide means to evaluate and to establish the basis for internal improvement programs. Cost of conformance are those costs incurred by measures to prevent permanent failure risks. Cost of non-conformance represents a waste of resources in the broadest sense. They arise on the one hand by an additional effort that is required by a non-qualifying service provision. On the other hand, they are generated by economic losses in production due to not qualifying products.

Cost of conformance is divided in two sub groups, prevention costs and appraisal costs. Costs of non-conformance can be divided in appraisal costs and failure costs (Bruhn and Georgi, 1999, Bredahl and Northen, 2004, Nöhle, 2004):

1) Prevention costs generated by activities that are undertaken specifically to avoid a non-qualifying quality.
2) Appraisal costs incurred by measuring, evaluation or audit activities of ensuring compliance of the power used by certain norms, standards and requirements.
3) Failure costs arise because of activities which are caused by the lack of power and accordance with certain standards and requirements.
    a. Internal failure costs arise from internal defects and dealt with by discarding or repairing the defective items.
    b. External failure costs arise from defects that actually reach customers.
    c. Direct failure costs are costs for scrap, costs arising from contractual and legal liability
    d. Indirect failure costs are costs of handling errors and costs for late delivery

In the present case, the costs of the monitoring service, the appraisal costs of PRDC and to derive the SI per farm, were determined with 1,148 € per year (table 4.1). The farmer bears the costs. Those are the costs of monitoring blood sampled at slaughter on five viruses and bacteria, such as *Mycoplasma hyopneumoniae* (Mhyo), *Actinobacillus pleuropneumoniae serotype 2* (APP 2), swine influenza viruses (SIV), porcine reproductive and respiratory syndrome virus (PRRSV), and porcine circovirus type 2 (PCV2). Per year 30 samples were taken per farm. The number of samples is spread continuously over the years. Usually every second month five blood samples were randomly taken of a delivery at the slaughterhouse. The cost of sampling at slaughter, costs of transport to the laboratory and the electronic transmission of the laboratory results are included in the price. Further, a veterinarian farm visit of 90 minutes is included to interpret the laboratory results. The information exchange and communication of the results is online available and therefore for the net-chain coordinator, the grower association Southeast Bavaria, and the farmer less organizational effort is needed. As sampling is executed at slaughterhouse and not on farm none appointments with farm veterinarians have to been made, as it is necessary when sampling on farm level, e.g. in the case of TIGA (Czekala and Münster, 2013). Further, the following assumptions have been made for the monitoring service at slaughterhouse: 1) Farm consists out of one stable 2) Farmer deliveries year around to the same slaughterhouse 3) The samples size is designed for the pilot farms, in detail farm sizes between 680 and 3,500 stable places 4) The samples size is adapted to the used pathogen pattern.

Table 4.1 Appraisal and prevention costs in applied scenarios

<table>
<tr><th>Cost of quality</th><th colspan="2">Variables</th><th>Lower limit</th><th>Upper limit</th><th>Assumptions</th></tr>
<tr><td>Appraisal Costs</td><td colspan="2">Monitoring service per year</td><td colspan="2">1,148 €</td><td>1. 30 blood samples analyzed on five pathogens
2. sampling costs at slaughter
3. transport to the laboratory
4. electronic transmission of the laboratory results
5. veterinarian farm visit of 90 minutes
6. organizational effort at the net-chain coordinator
Farmer bears the costs.</td></tr>
<tr><td rowspan="6">Prevention costs</td><td rowspan="4">Vaccination of piglets</td><td>one vaccination per piglet</td><td>1.50 €</td><td>2.50 €</td><td rowspan="4">The farmer, fattening level, can order piglets vaccinated for PRRSV, PCV2, Mhyo or APP2. Farmer bears the costs.</td></tr>
<tr><td>two vaccinations per piglet</td><td>3.00 €</td><td>5.00 €</td></tr>
<tr><td>three vaccinations per piglet</td><td>4.50 €</td><td>7.50 €</td></tr>
<tr><td>four vaccinations per piglet</td><td>6.00 €</td><td>10.00 €</td></tr>
<tr><td rowspan="2">Piglet quality</td><td>one star quality</td><td>5.00 €</td><td>10.00 €</td><td rowspan="2">The farmer, fattening level, can order different piglet qualities.
Farmer bears the costs</td></tr>
<tr><td>two star quality</td><td>7.50 €</td><td>15.00 €</td></tr>
</table>

In the present cases, vaccination costs can be seen as prevention costs of PRDC. Using the information through the analyzed blood sampled at slaughter on the presence of five pathogens PRRSV, PCV2, SIV, Mhyo and APP2 enables the farmer to decide which vaccination strategy to apply. It is standard routine in practice to use ELISA results to decide whether a vaccination is applicable or not. Each piglet vaccinated aroses extra cost. At the moment four vaccines are available for the PRDC, such as PRRSV, PCV2, Mhyo and APP2. Vaccinations are used most often to respiratory disease prevention (Fachinger et al., 2008, Martelli et al., 2013).

The break even of the monitoring service was calculated from the view point of the farmer who buys piglets. Vaccination of piglets for PRRSV, APP2, PCV2 and Mhyo are taken into account. The lower limit is 1.50 € and the upper limit is 2.50 € for each piglet vaccinated for one of the five pathogens (table 4.1). In the sum four scenarios were tested for each lower and upper limit.

Another alternative of prevention costs is buying higher piglet quality, e.g. free from PRRSV. Farms with a high pathogen pressure in blood sampled at slaughter are not advised to high quality piglets. One star piglets are calculated with an extra cost of 5.00 € (lower limit) and two stars piglets are calculated with an extra of 7.50 € (lower limit) in scenario one. In the second scenario one star piglets are calculated with 10.00 € extra (upper limit) and two stars piglets with 15.00 € (upper limit) (table 4.1). Based on the appraisal costs prevention costs can be saved, due to the fact that a farm with a high pathogen pressure needs no one or two stars quality piglets.

4.3.2 Model to calculate financial ratios and description of two scenarios

The gross margins per stable place were used to compare the pig herds. For calculating the gross margin, the average daily growth rate, average feed conversion rate and the stable size were changed in the model of ABAB Consultants B.V. (see appendix figure A.13). To make the farms comparable the following parameters were fixed under the two scenarios for each herd and fattening period: 1) price per piglet 2) starting weight equaled 3) price per kilo meat 4) feed costs per kilo meat 5) transportation costs per pig 6) mortality was calculated with zero percentage due to fact that larger stable sizes would be in disadvantage 7) occupancy of the stable 8) sold weight in kilo. The output of the model was gross margin per year. The gross margin was divided by the stable size to derive the gross margin per stable place. The gross margin per stable place was selected instead of gross margin per sold animal to enable a more comprehensive comparison between the farms.

The two scenarios were used to calculated the spread of the financial ratios. Therefore three variables were changed, price per piglet, price per kilo meat and feed costs per kilo meat (table 4.2). The differences between lower limit (scenario one) and upper limit (scenario two) are 10 € per piglet, 38 € Cent per kilo meat and eight cents feed costs per kilo meat.

Table 4.2 Two scenarios to calculate gross margin per stable place

Variables	Lower limit Scenario 1	Upper limit Scenario 2
price per piglet equaled	50 €	60 €
starting weight	25 kilo	25 kilo
sold weight	97.2 kilo	97.2 kilo
price per kilo meat	1.52 €	1.90 €
feed costs per kilo meat	0.27 €	0.35 €
transportation costs per	1 €	1 €
mortality rate	0 %	0 %
occupancy of the stable	100 %	100 %

4.3.3 Estimation point of failure costs and prevention costs

The estimation point is the framer and not the grower association, the slaughterhouse, the veterinarian, the consumer or other social groups. The financial value of PRDC, accruing to particular individuals such as farmers, are considerate, not the public or social economic value. McInerney and Turner (1989) stated that the private costs are the easiest figures to estimate and get the highest accuracy. Therefore, neither direct public expenditures nor indirect losses and expenditures are included arising in the wider economic system. This chapter is concerned with the farm management decisions at the level of the herd and not concerned with policy or planning decisions at regional or national level. Farm management decisions are based on financial criteria (Perry et al., 1999). Optimization strategies of animal production diseases in farm management are consistent with farmer's profit-maximizing objectives.

4.3.5 Statistical methods

The statistical package SPSS 20 (IBM SPSS 20) was used. ANOVA, linear regression, and backward multivariate linear regression analysis were conducted. For the multi-regression models, Durbin-Watson statistics were applied to test the assumption of independent errors. Values close to two indicated that the assumption of independent errors was tenable. A multivariable linear regression analysis with a backward elimination procedure was run to determine the most influential factors. Briefly, first, all predictor variables were entered into the model. The weakest predictor variable ($p > .05$) was removed and the regression re-calculated. If this significantly weakened the model, the predictor variable was re-entered. Otherwise, it was deleted. This procedure was repeated until only the significant predictor variables and predictors that were part of a significant interaction effect remained in the model (Crawley, 2002).

4.4 Results

4.4.1 Distribution of gross margin between farms and fattening periods

The 20 investigated farms show different gross margins per stable place. The gross margin per stable place varies between 17.90 € (fattening period one in scenario one) and 119.51 € (fattening period two in scenario two) (table 4.3). A detailed view on the gross margin per stable place indicates that herd 16 belongs to the group of farms with the highest gross margin per stable with a maximum of 0.24 points in SI in period three and four (details in Appendix). The gross margins per stable of herd 16 vary in scenario one and two between 96.80 € / 119.51 € and 82.92 € / 101.71 €. In contrast, farms with an SI higher than .75, like for example in herd 12, varies between 50.71 € / 61.10 € and 54.81 € / 66.03 € in scenario one and two.

Table 4.3 Minimum and maximum in gross margin per stable place per fattening period under two scenarios

	Scenario	Fattening period 1	Fattening period 2	Fattening period 3	Fattening period 4
Minimum	1	17.90 €	48.58 €	41.36 €	31.71 €
	2	19.15 €	58.33 €	48.72 €	38.04 €
Maximum	1	82.92 €	96.80 €	84.26 €	85.71 €
	2	101.71 €	119.51 €	103.97 €	105.44 €

4.4.2 Correlation between gross margin per stable place and serological indicator

In two out of four fattening periods the SI is significant correlated with the gross margin per stable place (table 4.4). The SI and the gross margin per stable place are significant correlated in the first period -.584 (p < .01) and the second period -.656 (p < .01). In the fourth fattening period the correlation is close to significance.

Table 4.4 Correlation coefficients between serological indicator and gross margin per stable place

		Serological indicator			
	Scenario	Period 1	Period 2	Period 3	Period 4
Gross margin per stable place	1	-.584 / .007**	-.656 / .003**	-.365 / .164	-.476 / .073
	2	-.584 / .007**	-.653 / .003**	-.361 / .169	-.473 / .075

Correlation coefficient and p – value; Pearson correlation coefficient two-tailed
*P < .05 **P < .01 ***P < .001

The failure costs of PRDC on farm level can be calculated by the application of the SI as indicator of farm respiratory health status. The linear regression models are significant for the first and second period. Period four is close to significant level (table 4.5). A SI of one will lead to halve the gross margin per stable place (table 4.5). Consequently, the failure cost of PRDC vary between 32.14 € and 52.98 € gross margin per stable place. As the SI represents the pathogen pressure on farm, the decision makers can derive concrete measurements to improve the situation on respiratory health.

Table 4.5 Results of the linear regression analysis with gross margin per stable place as depend variable and serological indicator as independent

Period	Scenario	Constant	ß + SE (ß)	P value	Durbin Watson	R-square	n
1	1	68.12	-32.14 (10.53)	.007	1.69	.34	20
	2	83.14	-41.02 (13.43)	.007	1.69	.34	20
2	1	82.60	-41.83 (12.02)	.003	1.21	.43	18
	2	101.49	-52.98 (15.35)	.003	1.21	.43	18
3	1	71.42	-20.46 (13.94)	.164	2.03	.13	16
	2	87.29	-25.91 (17.88)	.169	2.04	.13	16
4	1	75.59	-26.95 (13.79)	.073	2.14	.23	15
	2	91.04	-34.44 (17.79)	.075	1.98	.23	15

To enable a more focused improvement of the failure costs the most influential pathogens on the gross margin per stable place are determined multivariable linear regression analysis with a backward elimination procedure. In two out of four investigated fattening periods the gross margin per stable place is mainly influenced through the presence of PRRSV (table 4.6). PRRSV decreases the gross margin per stable place by 21.8 € (scenario 1) and 27.8 € (scenario 2) in period one, and 24.7 € (scenario 1) and 31.2 € (scenario 2) in period two. In the third fattening period APP2 decreases the gross margin by 16.2 € (scenario 1) and 20.7 € (scenario 2). However the p-values of the independent variable is not significant. In period four PCV2 decreases the margin by 22.5 € (scenario 1) and 29.1 € (scenario 2).

Table 4.6 Significant relationships in backward multi-variable linear regression analysis, regression parameters (ß), standard error of regression parameters (SE (ß)), P values and Durbin-Watson values

P	DP	Sce	Constant	Significant independent variable	ß ± SE (ß)	P value	Durbin Watson	R^2
1	GM	1	69.33	PRRSV	-.218 (.065)	.004	1.358	.38
		2	84.67	PRRSV	-.278 (.083)	.004	1.392	.38
2	GM	1	81.62	PRRSV	-.247 (.060)	.001	1.345	.51
		2	100.21	PRRSV	-.312 (.077)	.001	1.345	.51
3	GM	1	64.97	APP2	-.162 (.085)	.078	1.889	.21
		2	79.18	APP2	-.207 (.109)	.079	1.903	.21
4	GM	1	72.05	PCV2	-.225 (.076)	.011	1.880	.41
		2	86.67	PCV2	-.291 (.097)	.010	2.035	.41

DP = Dependent variable, Sce = Scenario, GM = Gross margin per stable place in €

4.4.3 Break even between monitoring service and prevention costs

Alternative one – Avoiding prevention cost, vaccination of PRRSV, PCV2, Mhyo, or APP2, through analyzing blood sampled at slaughter

The cost of the monitoring service is covered when 766 piglets per year (scenario one) can be bought without one vaccination, for example PRRSV vaccination. The results of the monitoring service, which includes a farm visit of a veterinarian, enabled the conclusion not to invest in PRRSV vaccination or another vaccination as prevention for PRDC. If two vaccinations, can be saved then the break even is reached by 383 piglets. 256 piglets is the break even if three vaccinations are not necessary and break even by 192 piglets without four vaccinations (table 4.7). In the scenario two, price 2.50 € per vaccination per piglet, the break even is 460 piglets for one saved vaccination per piglets, 230 piglets for two saved vaccinations per piglet, 154 piglets for three saved vaccinations per piglet and 115 piglets for four saved vaccinations per piglet.

Table 4.7 Break even in number of piglets not vaccinated based on the information of blood analyzed at slaughter

	One saved vaccination per piglet	Two saved vaccinations per piglet	Three saved vaccinations per piglet	Four saved vaccinations per piglet
Break even Scenario 1	766 piglets	383 piglets	256 piglets	192 piglets
Break even Scenario 2	460 piglets	230 piglets	154 piglets	115 piglets

Example saving prevention costs in the case of a farmer who buys 4000 piglets per year. The analysis of blood showed that PRRSV has no relevance for his farm. The farmer saved vaccination costs of 6.000 € (PRRSV vaccination per piglet 1.50 €) based on the analysis of blood at slaughter and invested for this information 1,148 € by participating in the monitoring program. Consequently, the benefit of saving financial resources is 4.852 € in scenario one and 8.852 € in scenario two (figure 4.1 and figure 4.2). Benefits of saving financial resources, unspent costs, for 4000 piglets are 10.852 € for two saved vaccinations, 16.852 € for three saved vaccinations and 22.852 € for four saved vaccinations (scenario one). In scenario two, the saved financial resources are 8.852 €, 18.852 €, 28.852, and 38.852 € (figure 4.2).

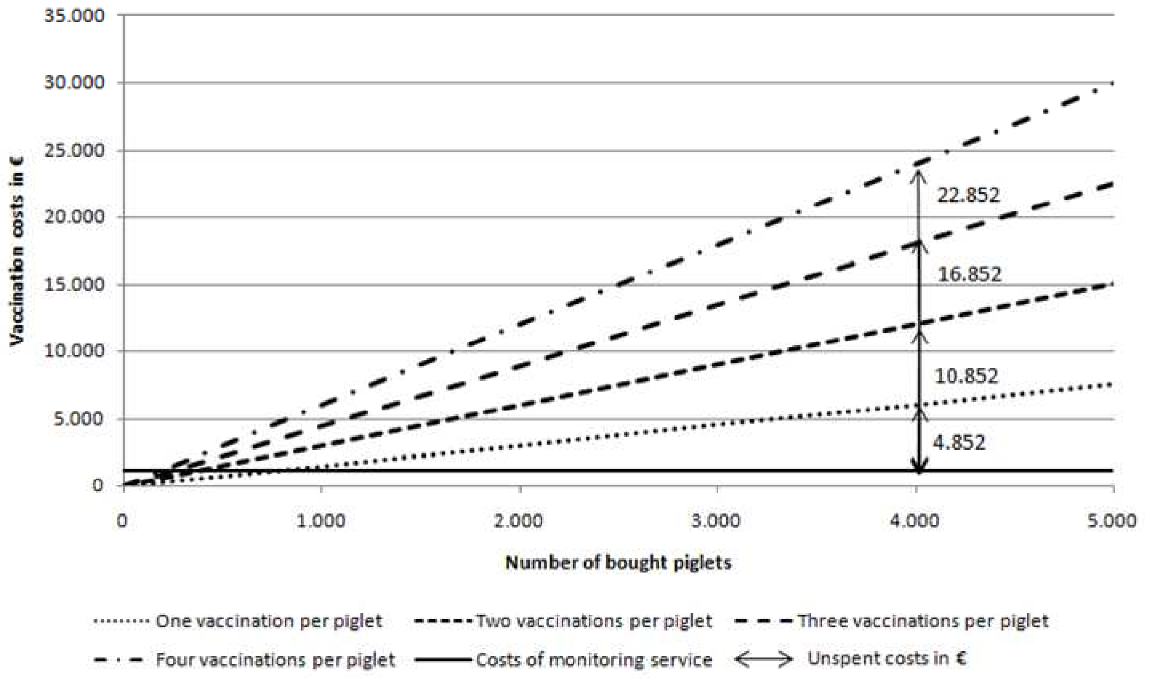

Figure 4.1 Costs of four possible vaccination strategies in relation to costs of monitoring in scenario one

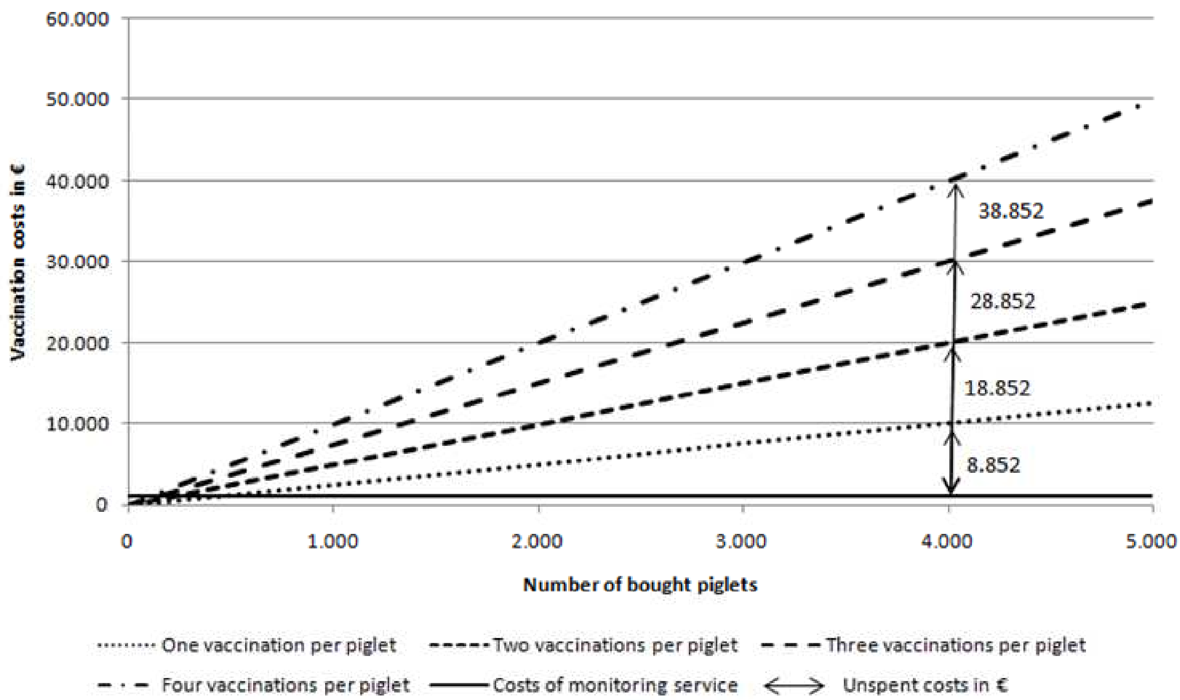

Figure 4.2 Costs of four possible vaccination strategies in relation to costs of monitoring in scenario two

Alternative two - Avoiding prevention costs of PRDC through analyzing blood sampled at slaughter with the decision on the piglet quality

When participating in the monitoring service the break even in the number of piglets not bought with one star quality or two stars quality ranks between 230 and 154 in scenario one (lower limit) and 115 and 77 piglets in scenario two (upper limit). The decision of not buying star or premium piglets is rooted in the pathogen pressure found on the farm through analyzing blood sampled at slaughter. For example PRRSV free piglets and without PRRSV vaccination miss the immunity to perform on a farm with high pathogen pressure on PRRSV (table 4.8).

Table 4.8 Break even between piglet health status and pathogen pressure on fattening farm

	Piglet quality – One Star	Piglet quality – Two Stars
Break even scenario 1	230 piglets	115 piglets
Break even scenario 2	154 piglets	77 piglets

The results of the monitoring and inspection strategy may enable farmers to decide what quality of piglets to order. Not for every farm high quality piglets are useful. However, as the pathogen pressure is different, the farmer can decide what piglet quality would best suit the present farm situation. If the pathogen pressure is high this famer may be advised not to order 4000 high quality piglets. Consequently the farmer save financial resources of 18.852 € not buying one star quality, five euro extra per piglet and 28.852 € if not buying two stars piglet quality of 7.50 € extra in scenario one (figure 4.3). In scenario two with extra costs of 10.00 € per piglet (One Star) and 15.00 € per piglet (Two Stars), financial resources of 38.852 € and 58.852 € are saved (figure 4.4).

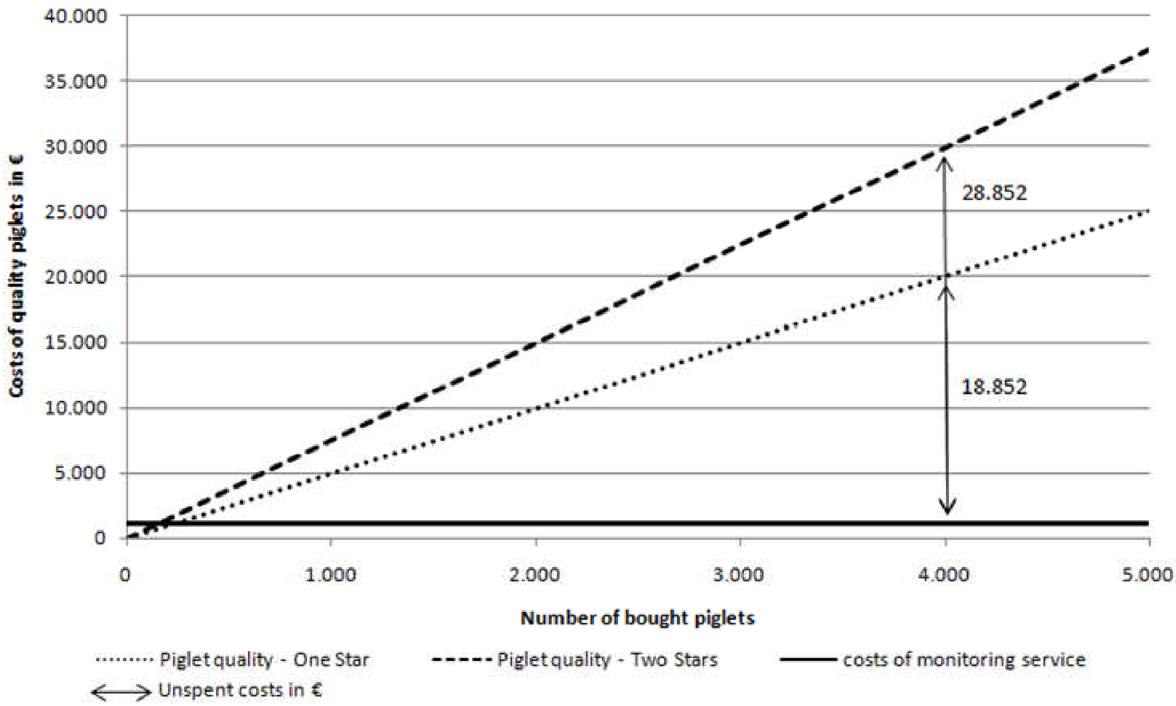

Figure 4.3 Costs of two possible qualities of piglets with an extra costs of 5 € per piglet (One Star) and 7.50 € per piglet (Two Stars) in scenario one

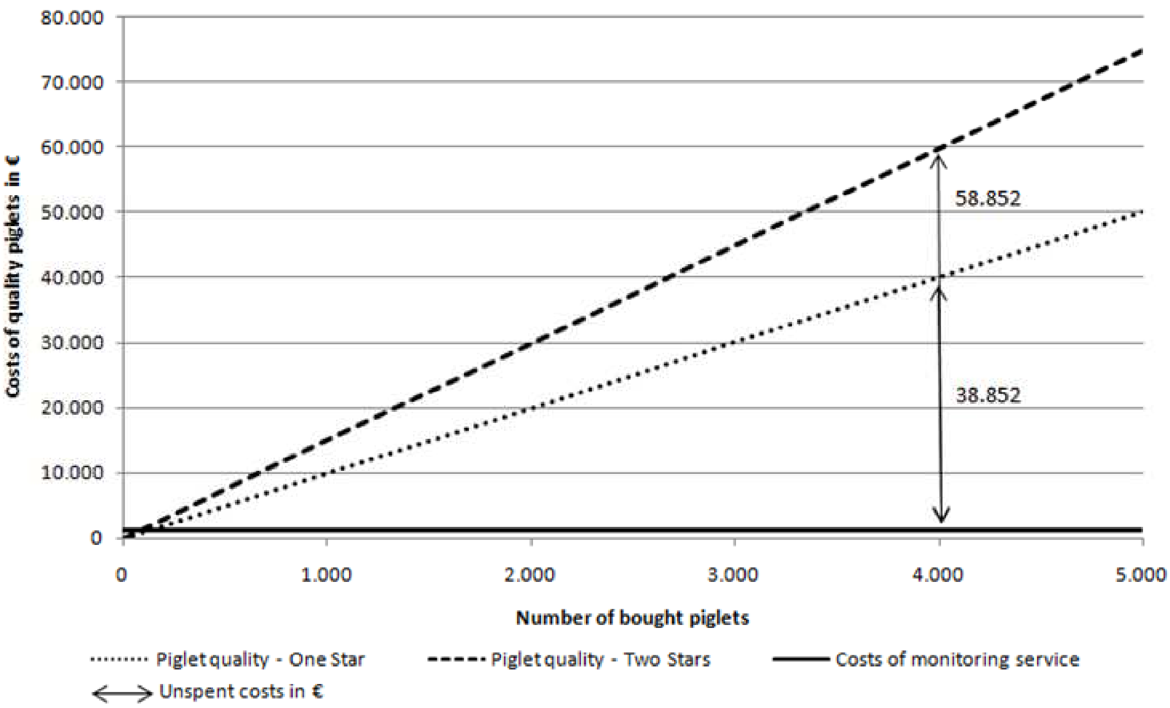

Figure 4.4 Costs of two possible qualities of piglets with an extra costs of 10 € per piglet (One Star) and 15 € per piglet (Two Stars) in scenario two

4.5 Discussion

The present chapter indicated significant correlations between SI and gross margin per stable place in two out of four investigated fattening periods. The SI based on blood sampled at slaughter and analyzed via ELISA serology on five relevant pathogens associated with PRDC. Pigs were selected at random to ensure that the slaughterhouse blood sampling was fully representative of the herd. The average daily growth rate and average feed conversion was submitted by the farms. Due to this the risk arose that farms have cheated concerning their technical herd performance. The herds included in this study were not selected at random from the entire population of Southeast Bavaria herds and, therefore, may not be representative of this population as a whole. Nevertheless, the herds were selected in such a way that they had characteristics that made them comparable to other pig farms.

The value of Durbin Watson varies in the linear regression model of gross margin per stable place and SI between 1.21 and 2.14. In the regression models derived based on the multivariable linear regression analysis with a backward elimination procedure backward exclusion of variables of the most influential pathogens the value of Durbin Watson is between 1.35 and 2.14. For the regression models the Durbin-Watson value was close to two, which means that the residuals are uncorrelated. None model did not produce values below 1 or greater than 3.

In the fattening periods three and four, there is no significant relationship between SI and gross margin. Reasons for this may the seasonal influence, because fattening period three and four were sampled in January and March. This should be validated in a new research project, whether seasonality has an influence on the results. Further, the missing data on the herd performance in period three and four may results in less significance. The missing results of gross margin may also distort the results of the study.

Using market prices for the economic evaluation of information should be done carefully. Some sort of market price can be associated with economic value of a product (McInerney et al., 1991). The danger could arise that the selected market price is not representing the true economic value of the product, such as feed or piglet price. In the present case, the used prices were discussed with experts.

The gross margin per stable place was used instead of using the gross margin per pig to enable a more comprehensive comparison between farms. The gross margin per pig would neglect the amount of sold pigs per year and by this the gross margin is reduced. In contrast, the gross margin per stable place is even higher when more runs per year increase.

To use of the SI as predictor of respiratory health may be under discussion. Chapter three showed that there are strong correlations between clinic signs of PRDC and SI as well as SI and percentage of pig pneumonia per herd. Therefore, the SI can be used to explain the difference in gross margins caused by PRDC.

The practical implementation of a financial analysis is facing a series of problems. First, after the implementation of a decision it is possible that at the same time almost different changes take place that lead to the same result (Horton, 1994). The present financial analysis is run based on the state of the art analysis. The present chapter did not measure the benefits of an executed change based on the results of analyzing blood sampled at slaughter. Second, in financial analysis it is difficult to identify and to quantity costs and benefits. The ability to identify and quantify the costs and benefits depends on the cost and benefit awareness and the used setting the participants have. Therefore, the present study focused only on farm level. As costs of diseases only ADGR and AFCR are taken into account. Third, consumed resources for which no market prices are available have to be estimated. However, estimates are made under uncertainty. Therefore, it is recommended to increase the validity of the analysis by using instead of individual values, a value interval with upper and lower limits for the cost-benefit analysis (Arrow et al. 1996). In the present analysis the market prices for feed are included. Those are taken from the LKV Bayern benchmark report 2012. The price for piglets and pigs are based on the market price. Additionally, the recommendation has been followed to use an interval. Fourth, in the classical financial analysis, all stakeholders influenced by a decision were involved. The various stakeholders in the in the pork value chain have different, possibly conflicting perspectives or cost and benefits of a decision. No inter-organizational cost-benefits analysis is accomplished. One stage of the pork value chain are involved, fattener.

The costs of the monitoring service were determined in the pilot case with 1,148 € per farm. However, a farm could consist of more than one stable. Each stable could have a different pathogen schema due to different piglet origins. Therefore, it is advised that for each stable the monitoring program is applied. The sample size should be adapted if other pathogens are included according to their prevalence.

The calculated break even may vary under practical circumstances. However, it could be shown that the break even for the monitoring service is reach early. This could be an incentive to apply the monitoring service.
The calculated failure costs of PRDC are estimates based on two scenarios. However, the estimates gave an impression how important it is to focus on animal health.

4.6 Conclusion

The formulated hypothesis, the monitoring and testing strategy enables to explain the financial impact of production diseases on farm level and that the benefits of this strategy outweigh the costs, was accepted. As the SI indicates that PRDC could halve the gross margin per stable place that should be an incentive for farms continuously to improve the herd health status. The presence of PRRSV, APP 2 and PCV 2 is of great significance to reduce gross margin per stable place. Insights in the pathogen pressure enable the ELISA analysis of blood sampled at slaughter and by this the opportunity arose to control the KPI gross margin per stable place. Vaccination decisions on farm can be more focused and avoided prevention costs on vaccination of pathogens lead to an early breakeven point of 115 bought piglets.

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Chapter 5 - Two dimensional farm benchmark based on two key performance indicators

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5.1 Abstract

Aggregation of information about herd health status in relation to technical performance is a challenge. A two dimensional benchmark was developed to get a simple representation of this kind of information to help farmers and farm veterinarians to improve the technical performance and health status. Therefore, two indicators were developed that define technical performance and respiratory health. A four square table was used to visualize the position of farms on the two indicators. The objective of this chapter was to assess the applicability of the four square table to promote the decision making on farm level.

Therefore, the average daily growth rate, feed conversion rate, percentage of pig with pneumonia and the serological profile based on blood sampled at slaughter was documented over four fattening periods on 20 pig farms in Southeast Bavaria. Those information were summarized in two indicators, technical performance and respiratory health. In three out of four fattening periods the developed KPI on technical performance and the KPI on respiratory health were significant correlated, in period one .63 ($p < .01$), in period two .57 ($p < .01$), and in period three .57 ($p < .05$). The position of farms in a four square table over the four fattening periods showed clearly differences between the farms and the fattening periods.

The ranking of the 20 farms on the respiratory health and technical performance over the four investigated fattening periods enabled to identify three patterns (1) farms with a stable position, (2) moderate instable position and (3) highly instable position. No clear pattern on production parameters was found on individual farm level, such as production system or number of piglet origins.

However, the analysis of blood sampled at slaughter provides more insights into respiratory health and can explain the identified pattern but even more the change in respiratory health between the fattening periods. No clear pattern could be found to be risk factors of lower respiratory health, such as type of herd, size or hygiene policies. This underlines that blood analyses enabled an explanation of the respiratory health performance, which promotes better decision making.

5.2 Introduction

The findings of chapter four promote the interest to aggregate the different KPIs and consequently to enable a benchmark on farm level and to increase the motivation of farms continuously to improve on those KPIs. The actors in the pork supply chains have more and more information available on pig herd health status and technical herd performance. Information about the health status is coming from serological screenings, findings in the slaughter line and information from the veterinarian for example. A more recent source of information of the same testing point is the analysis of blood sampled at the slaughterhouse (Düsseldorf et al., 2012). These data can be used to gain knowledge of pig herd health status on respiratory health (Düsseldorf et al, 2012). Pig herd health is of major concern for the economic performance of pig herds. Especially, the porcine respiratory disease complex (PRDC) is a challenging problem in intensive pork production systems (Fraile et al., 2010). PRDC results in high economic losses in modern pig production because of reduced growth rate, decreased feed conversion (Grest et al., 1997, Martinez et al., 2009, Martelli et al., 2009). Information on the technical performance, specifically daily gain and feed efficiency are generated by advocacy organizations or by the farmer himself during production process (LKV Bavaria, 2011). Consequently data on performance is available. In the last decades the collection of this data has become cheaper and data is gathered at many points along the supply chain (Lang und Petersen, 2012). It may nevertheless happen that all actors in the chain are overwhelmed by an increased information flood. Worst case, the information in this data is not used for the continuous improvement process of the entire chain, for example for the improvement of pig herd health status. To get useful information from the dataset KPIs can be used. Present decision tools are lacking accuracy to derive the right decision. For example, farms have only benchmarks on average daily growth rate or feed conversion rate (LKV Bavaria, 2011). However, the consideration of respiratory health as a limiting factor is neglected.

The concept of a four square table is often used in quality management. Ellebrecht (2012) ranked, based on the four square table, network coordinators according to their implementation level of quality management methods and coordination service offers. Additionally, Lang and Petersen (2012) applied a four square matrix to assess companies' abilities to implement an inter-organizational control strategy.

So far, only very rarely, there is a visual processing of information from technical performance perspective and respiratory health perspective. Mainly, that information is gathered on different stages of the production chain. A benchmark covering two production stages, on farm and at slaughterhouse, has been not tested yet. Further, a benchmark of farms based on two KPIs, health and performance, is lacking. In agriculture, benchmarks are often one-dimensional, mainly on performance. Combined benchmarks of technical and animal-related parameters were previously lacking.

The aim of the present chapter is to analyze the possibility to combine pig health status related indicators with fattening performance indicators in a four square table, where the axes represent a defined key performance indicator on the respiratory health and technical herd performance. The position of each of the 20 pig farms in the four square table is investigated over fattening periods. Further, the factors are investigated that could explain the position and its change between the four fattening periods.

The present chapter is testing the fourth hypothesis: The combination of health parameters and fattening performance parameters is suitable for implementation of internal and inter-organizational benchmarks and allows the identification of vulnerabilities.

5.3 Material and methods

5.3.1 Structure of the key performance indicators

Information were gathered on both, farm level and slaughterhouse. 20 pig farms were investigated over four fattening periods on average daily growth rate (ADGR), average feed conversion rate (AFCR), respiratory health and serological profile based on blood sampled at slaughter. AFCR and ADGR were assessed in 15 out of 20 herds by the Federal Bavarian consultancy (LKV Bayern), as it is routinely being done on these farms. The farmers provided the results on a pre-defined questionnaire after the fattening period. Farm characteristics were described already in chapter three (table 3.1).

The official meat inspection was used to assess the farm respiratory health. During the routine post-mortem meat inspection official personnel performed assessment of lung lesions. At this slaughterhouse, the following lesions were documented: percentage of pigs with middle-grade pneumonia (10 – 30% surface affected) and percentage of pigs with high-grade pneumonia (>30%). In the analysis, the total percentage of pigs with pneumonia was used without differentiating between middle-grade and high-grade.

The SI was calculated based on randomly collected blood samples of a randomly selected delivery of the fattening period. The blood was tested for antibodies of five pathogens associated with the porcine respiratory disease complex (PRDC): *Mycoplasma hyopneumoniae* (Mhyo), *Actinobacillus pleuropneumoniae serotype 2* (APP 2), swine influenza virus (SIV), porcine reproductive and respiratory syndrome virus (PRRSV), and porcine circovirus type 2 (PCV2). The SI was used to describe the overall sera reactivity per herd by one value. SI was calculated by the following formula, whereby P is the rate (%) of seropositive samples per pathogen, and SI ranges between 0 and 1.

Serological indicator = $(P_{PRRSV} + P_{PCV2} + P_{Mhyo} + P_{SIV} + P_{APP2})/500$

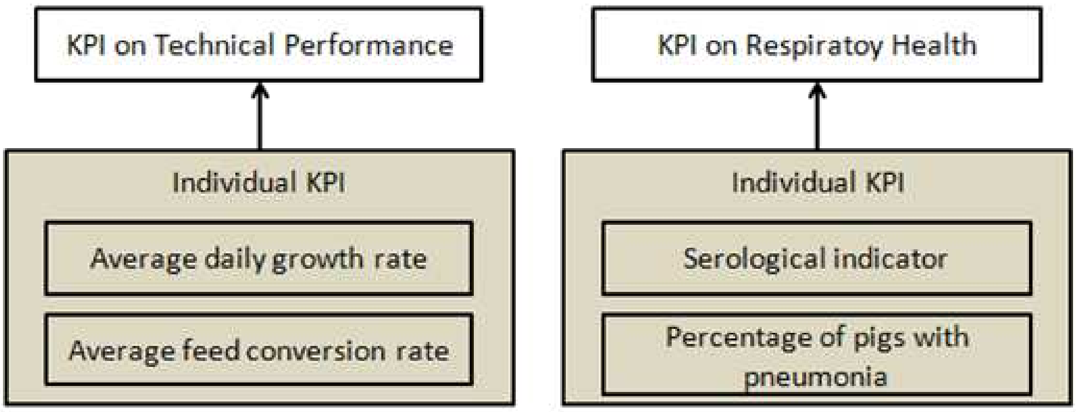

Figure 5.1 Structure of key performance indicators

5.3.2 Quartiles, assignment of codes and formula

The quartiles were calculated for ADGR, AFCR, percentage of pigs with pneumonia, and SI based on the results of the 78 fattening periods. The median for ADGR is 773g, 2.86 for AFCR, 7.66 % for pigs with pneumonia per herd and 0.49 points for the SI (table 5.1). The values of ADGR and AFCR are close to results of Federal Bavarian consultancy (LKV Bavaria 2011). Therefore, the quartiles can be assessed as valid and representative. For the quartiles of percentage of pigs with pneumonia and SI no references exist. Therefore, it was decided to calculate the ADGR and AFCR based on the present herds and not to use the LKV quartiles. Further, the quartiles were calculated based on the four investigated fattening periods. This is the same approach as used by the LKV Bavaria for ADGR and AFCR.

Table 5.1 Quartiles of average daily growth rate, average feed conversion rate, percentage of pigs with pneumonia and serological indicator

	ADGR	AFCR	% of pigs with pneumonia	Serological indicator
Third quartile	802	2.92	16.21	0.64
Median	773	2.86	7.66	0.49
First quartile	736	2.71	4.24	0.32

ADGR = Average Daily Growth Rate AFCR = Average Feed Conversion Rate

For each calculated quartile a code was assigned. The codes rank between zero and three. Hereby zero represents the worst quartile and three the best quartile. Herds with an ADGR less than or equal 736 g, an AFCR higher than or equal 2.92 kg, a percentage of pigs with pneumonia higher than or equal 16.21 and a SI higher than or equal 0.64 showed the worst performance (table 5.2).

Table 5.2 Codes of quartiles for key performance indicator ADGR, AFCR, percentage of pigs with pneumonia and serological indicator

Code	ADGR	AFCR	% of pigs with pneumonia	Serological indicator
0	≤736	≥ 2.92	≥ 16.21	≥0.64
1	737 - 773	2.91 - 2.86	16.20 - 7.66	0.63 - 0.49
2	774 - 801	2.87 - 2.72	7.67 - 4.25	0.48 - 0.33
3	≥ 802	≤ 2.71	≤ 4.24	≤ 0.32

ADGR = Average Daily Growth Rate AFCR = Average Feed Conversion Rate

The developed four square table bases on two key performance indicators. The first describes the technical performance based on ADGR and AFCR. The second describes the respiratory health performance based on SI and percentage of pigs with pneumonia per herd. The KPI on technical performance was calculated (formula one) based on the codes for ADGR and AFCR. A value close to zero means a worse fattening period result and the value one equals an excellent result. The same procedure is applied for the KPI on respiratory health, including serological profile and percentage of pigs with pneumonia (formula two). A worst respiratory health is indicated by zero and top level by one.

Formula 1

$$\text{KPI on technical performance} = \frac{(\text{Code ADGR} / 3) + (\text{Code AFGR} / 3)}{2} = 0 - 1$$

Formula 2

$$\text{KPI on respiratory health} = \frac{(\text{Code \% Pneumonia} / 3) + (\text{Code SI} / 3)}{2} = 0 - 1$$

5.3.3 Benchmark tool

The farms can be positioned in a four square table based on the two KPIs, technical performance and respiratory health. The abscissa (x-axis) shows the KPI on respiratory health. The ordinate (y-axis) represents the KPI on technical performance of the fattening period (figure 5.2). Each fattening period of the investigated farm is placed in the four square table.

Lang and Petersen (2012) and Ellebrecht (2012) used as well a four square table to rank organizations according to different objectives. Ellebrecht (2012) used as well the four square table and defined the quadrates as QM + CS stars, QM + CS dogs, QM questions marks and CS freeloader. Lang and Petersen (2012) used the terminology as well, AMOR stars, dogs, question marks and freeloader. The names stars, dogs, freeloader and question marks are used frequently on management level. However, they were not considered as useful in the agricultural consultancy.

Therefore the quadrates were labeled in the present situation as follows (figure 5.2):

1) Optimization expert: Those farms have a top level KPI on technical performance and respiratory health. The resources are fully exploited.
2) Optimization specialist: Those farms have either a top level KPI on technical performance or respiratory health. Either the resource technical performance or the resource respiratory health is fully exploited. Those farms can still optimize their KPIs.
3) Optimization newcomer: Those farms have worst level KPI on technical performance and respiratory health. Resources are not exhausted and the farmer has to learn how to improve on both KPIs.

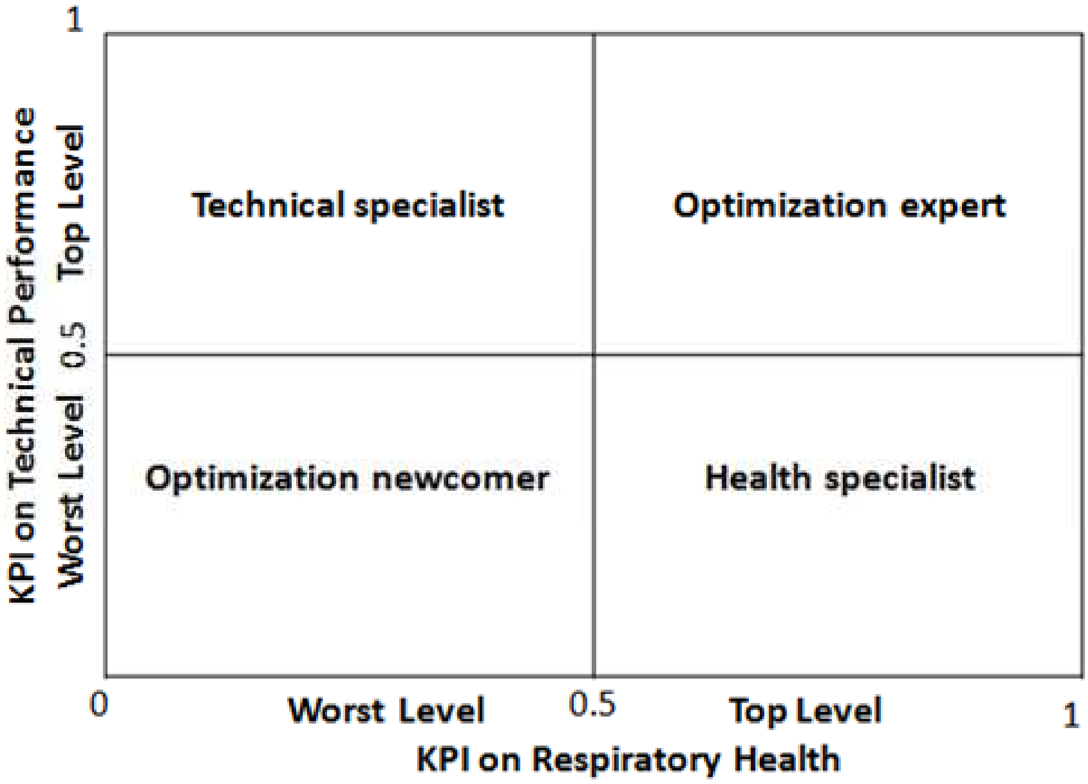

Figure 5.2 Benchmark systematic of farms for KPIs on technical performance and on respiratory health

Farms can only be assessed as optimization expert, specialist or newcomer if four out of four fattening periods were allocated to the same quadrate, this means a stable position. Otherwise the farms were characterized as instable or highly instable farms. Instable farms change their position over two quadrates. Highly instable farms changed their position over three or four quadrates.

5.4. Results

5.4.1 Correlation between technical performance indicator and respiratory health indicator

The KPI on technical performance and KPI on respiratory health are significantly correlated in three out of four fattening periods. The Pearson correlations coefficients vary between .57 and .67. R-square varies on a stable level and ranks between .33 and .39. Therefore, the chosen farm level benchmark tool can be assessed as reliable (table 5.3).

Table 5.3 R square, correlation coefficients and p values between KPI on technical performance and respiratory health in four fattening periods

	Fattening period	R^2	Correlation coefficient	p-value
KPI on technical performance and on respiratory health	1	.39	.63	.003**
	2	.33	.57	.008**
	3	.33	.57	.011*
	4	.16	.40	.092

*P < .05 **P < .01 ***P < .001

5.4.2 Benchmarks of farms

The arrangement of the farms in the four square table shows very large variation between the 20 investigated farms (figure 5.3). Five out of 20 farms have a stable position. Two out of this can be described as optimization exert and three as optimization newcomer. Nine out of the 20 farms show an instable position in the four square field. Those farms change their position over two quadrates. Six out of 20 farms show a highly instable position. Those farms changed their position over three quadrates. Not one farm has been observed to have a position in all four quadrates over the four fattening periods.

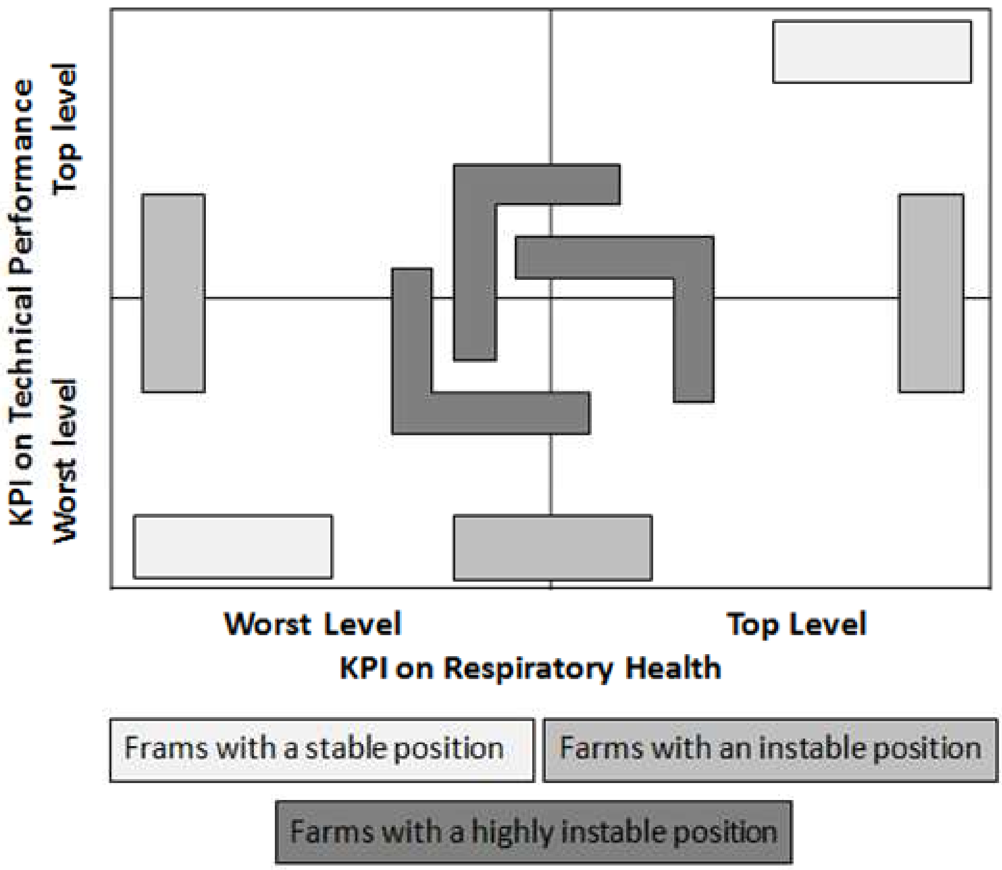

Figure 5.3 Position of twenty farms in the four square table over four investigated fattening periods

5.4.3 Patterns based on the benchmark

The ranking of the four investigated fattening periods of the 20 farms on the respiratory health and technical performance KPIs enabled to identify three patterns (1) farms with a stable position, (2) moderate instable position, and (3) highly instable position.

Stable position farms

Two farms have a stable top level KPI on technical performance and on respiratory health. Farm 16 und 17 are the optimization experts. Farm 16 had in the first, second and third fattening period the same score on technical performance and respiratory health (figure 5.4, other farms can be found in Appendix between figure A.14 and A.33). In the fourth fattening period the score of the respiratory health changed. The same occurs for farm 17, but here the score of the technical performance changed in period four.

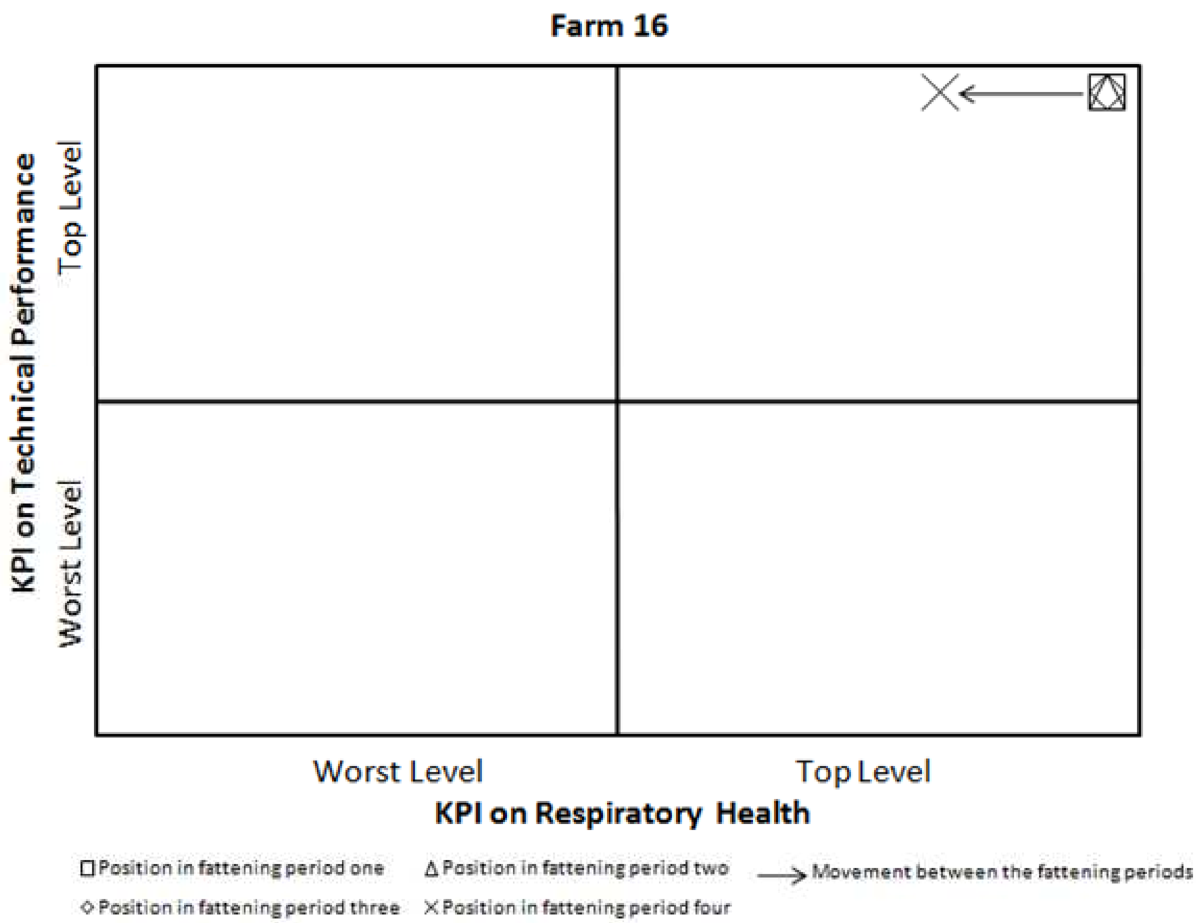

Figure 5.4 Example of stable top level respiratory health and technical performance farm

One of these two farms is fattening pigs and the other farm is producing in a closed farrow-to-finish system. The herd operating in an open system is sourcing the piglets year around from the same piglet origin. For both farms the distance to the next farm is more than two kilometers. Both farms have newly constructed stables (two respectively seven years old). Both produce in an all-in-all-out pen and cleaning after every fattening period the pen. Both work without disinfection. Both have Salmonella status and QS status one. Stable size was 1000 and 1100.

In contrast, three farms performed worst on both, the KPI on technical performance and respiratory health (figure 5.5). Farm four, 12 and 19 can be characterized as optimization newcomer. In the same manner to optimization experts, these farms produce pork in farrow-to-finish or fattening pigs. A difference to the optimization expert is that those farms source piglets from three to eight piglet origins per fattening period and the origins change. Further, the buildings are older (15 to 30 years). The department load is mainly continuous and due to this cleaning is only done once or twice per year. However one farm, farm 19, is applying all-in-all-out per department and cleaning after each fattening period and disinfection once or twice per year. Farm four and 12 apply no disinfection. However these farms had salmonella status and QS status one. Stable size varied between 750 and 1100 places.

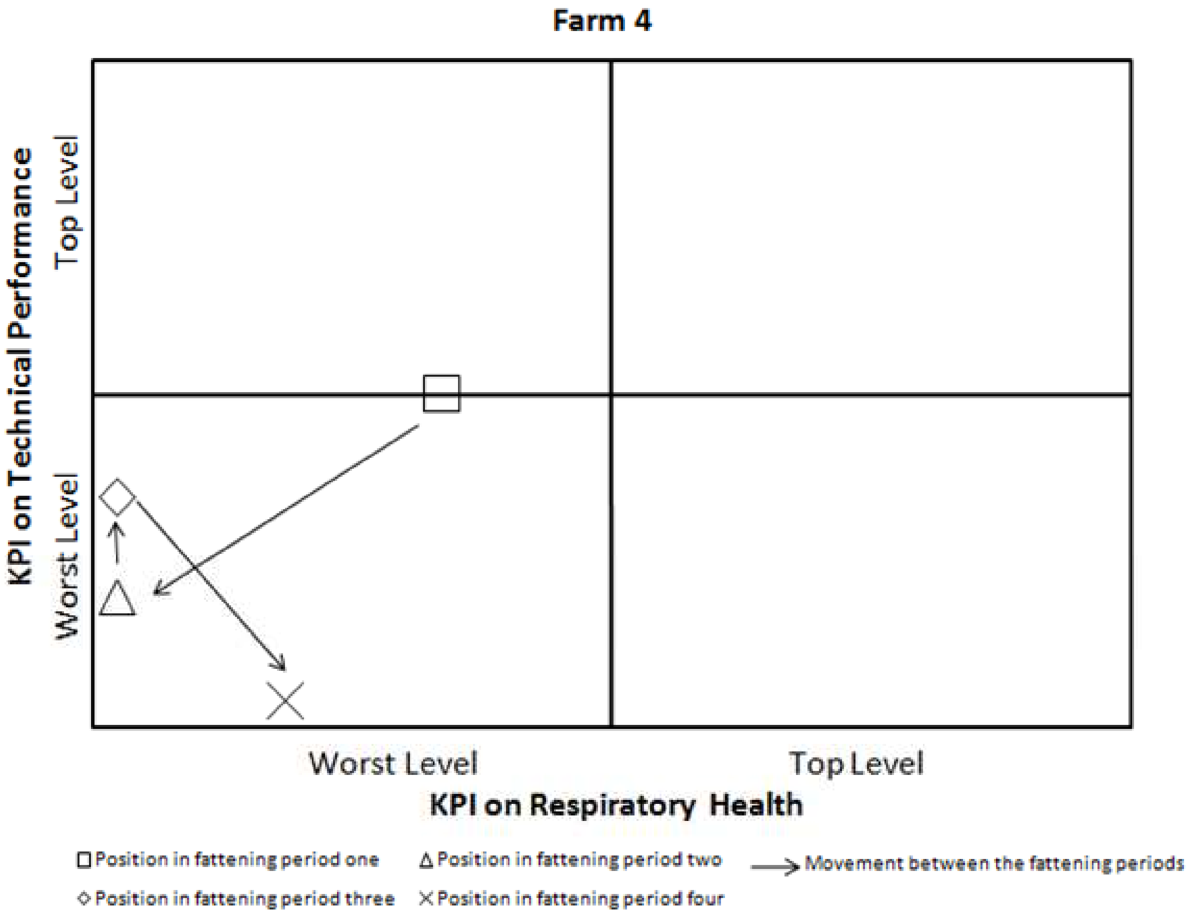

Figure 5.5 Example of stable worst level respiratory health and technical performance farm

Moderate instable position over two quadrates

Farms three, 14 and 15 with a top level KPI on respiratory health and changing KPI on technical performance produced pork either in farrow-to-finish or fattening pigs. For example farm 15 started with worst level KPI on technical performance and top level respiratory health in period one and reached in the fourth fattening period a top level KPI on respiratory health with top level KPI on technical performance (figure 5.6). Farms three and 14 sourced piglets from one or two piglet origins per fattening period. However, farm three is changing the piglet origin between the fattening periods, but focusing only on one piglet origin per fattening period. All three farms are working all-in-all-out per department and cleaning as well as disinfection after each fattening period. The stable size varies between

680 and 1200 places. The distance to the next farm with pigs is between 500 meters and one kilometer. All herds have salmonella and QS status one.

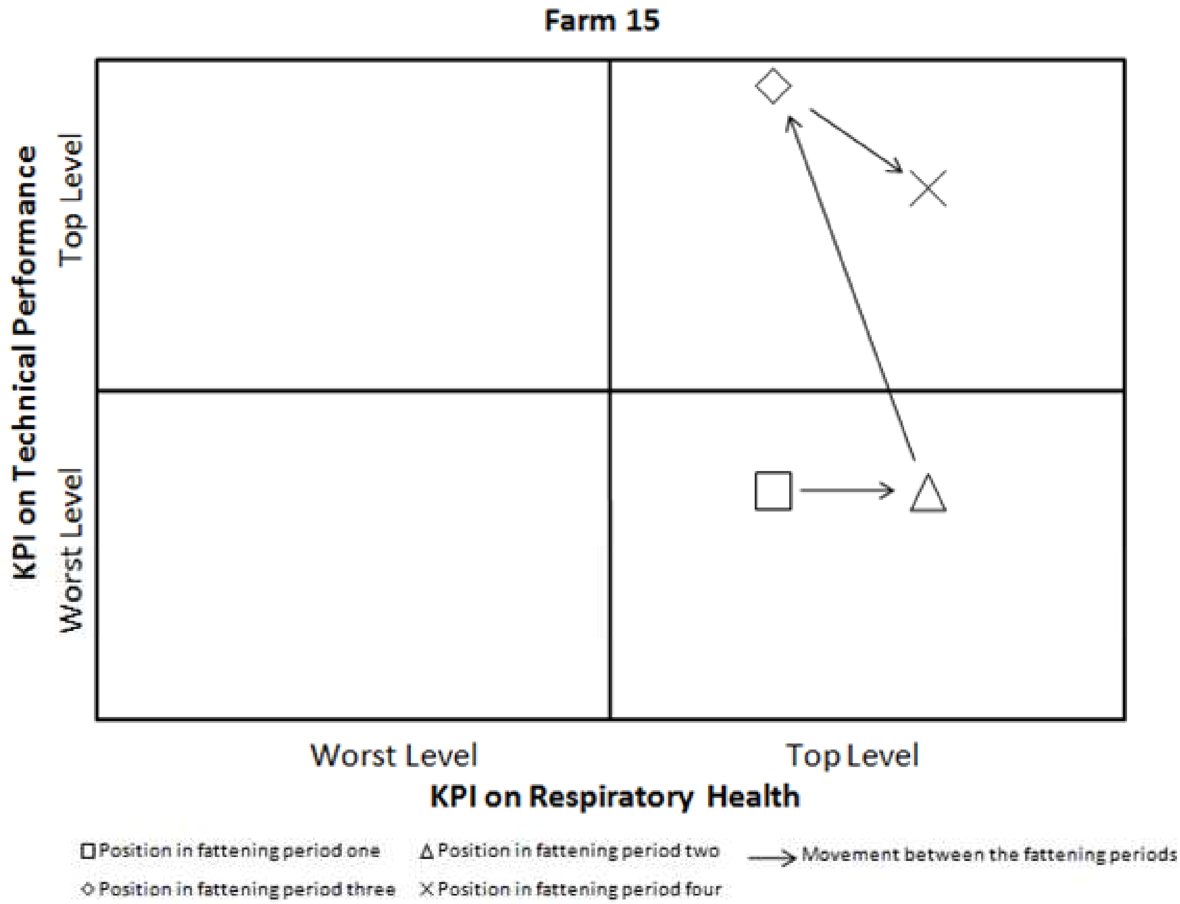

Figure 5.6 Example of stable top level respiratory health and changing technical performance farm

Farm two, six and ten with a worst level KPI on respiratory health system and changing KPI on technical herd performance are producing in a farrow-to-finish systematic and fattening pigs. Farm two sources the piglets from the same origin year around. Farm ten continuously changes between three origins (figure 5.7). Worst level KPI on respiratory health is maybe due to continuous load per department in farrow-to-finish systems without disinfection and cleaning once or twice per year on farm 6. Farm two does also no disinfection. Also a new stable, farm two, could lead to worst level respiratory health system. The stables size varies between 770 and 2400. The age of the stable varies between four 34 years. All the farms have QS status one as well as Salmonella status.

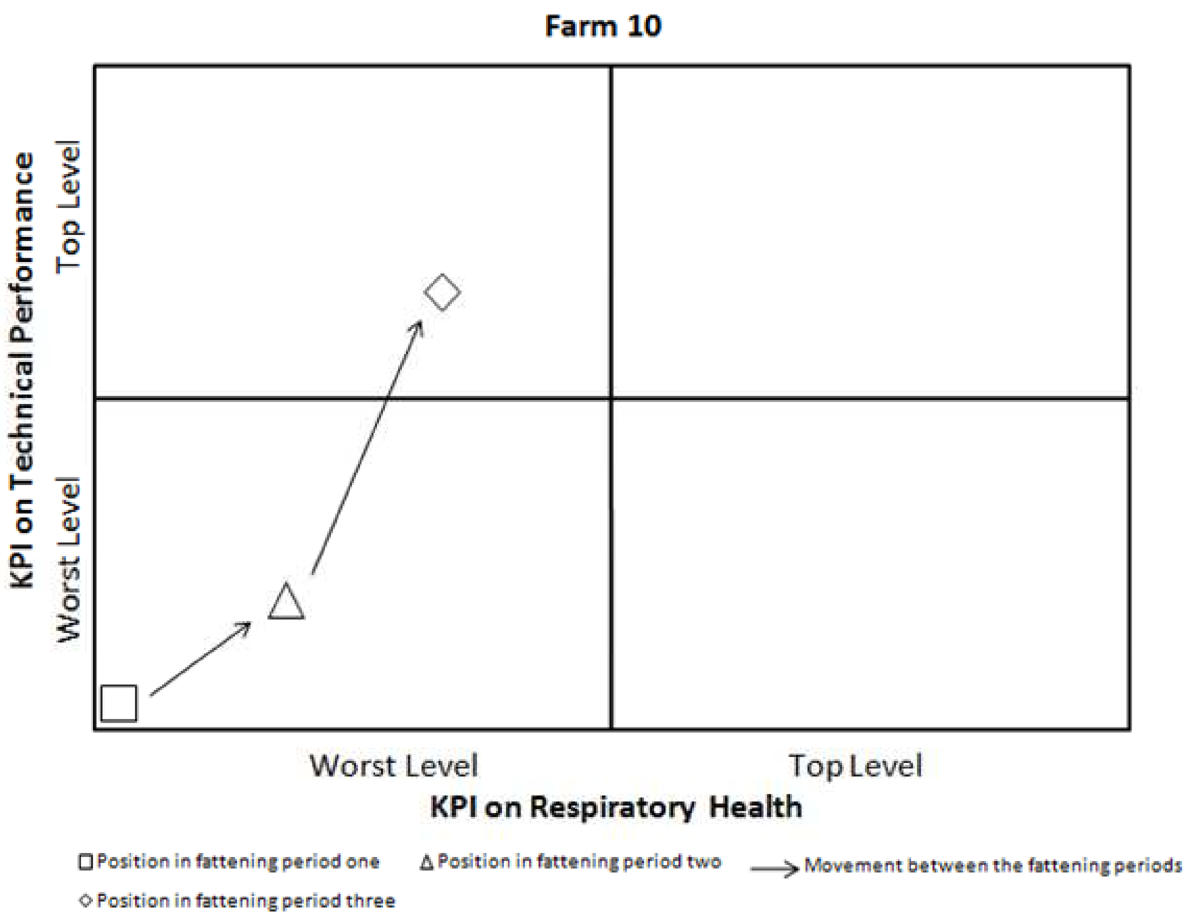

Figure 5.7 Example of stable worst level respiratory health and changing technical performance farm

Farm five, nine and eleven with a worst level KPI on technical performance and changing KPI on respiratory health are producing in farrow-to-finish systematic or fattening pigs (figure 5.8). The farms five and eleven in the open system source piglets every time from the same piglet origin, working in al-in-all-out department systematic and clean as well as disinfect the departments after each fattening period. Farm nine has a continuous load of the departments and does not disinfect after fattening. The distance to the next herd is less than 500 meters up to one kilometer. The age of the buildings varies between 24 and 33 years. Only farm five has Salmonella status two. All three have QS status one. The stable size varies between 550 and 1100.

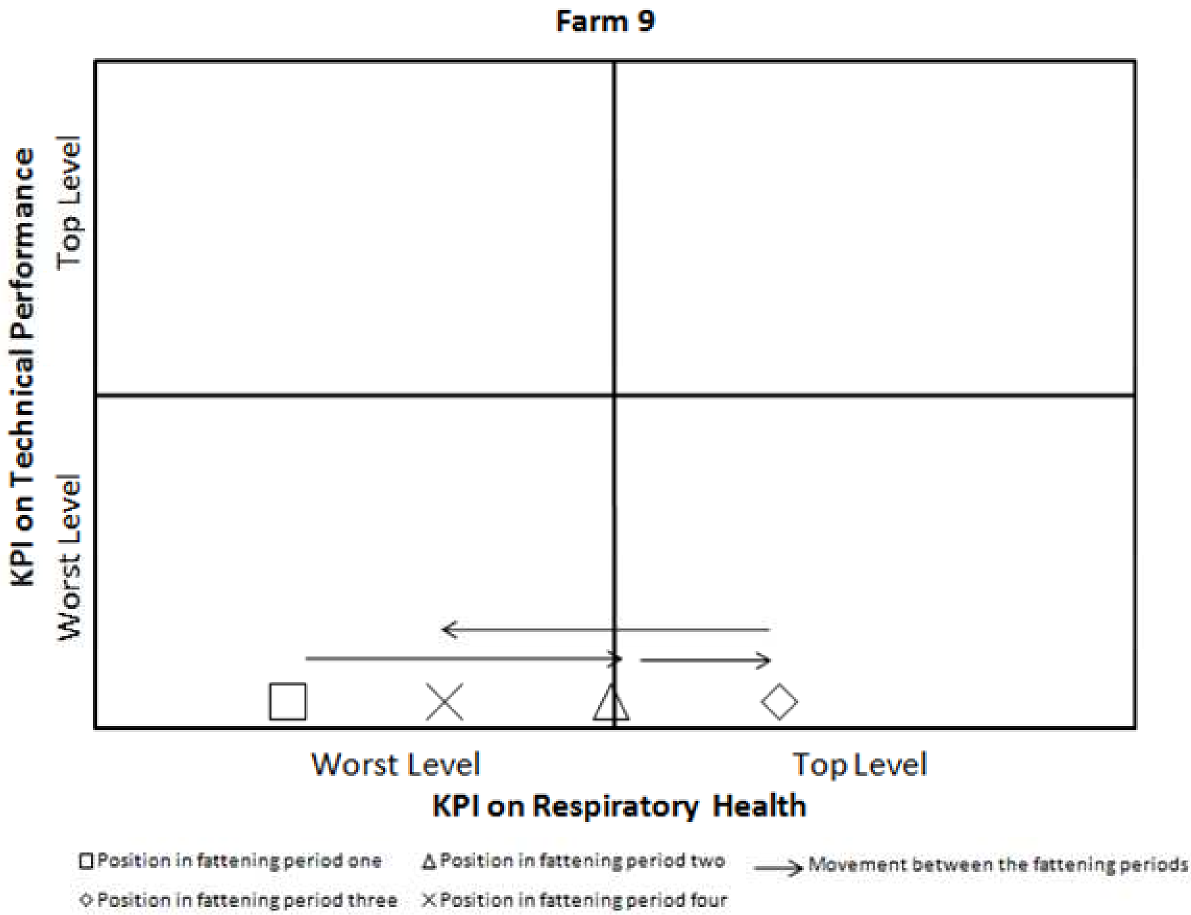

Figure 5.8 Example of stable worst level technical performance and changing respiratory health farm

Highly instable farms over three quadrates

No farrow-to-finish farm is highly instable. Highly instable farms on technical performance and respiratory health are all-in-all-out per department whit changing piglet origins (figure 5.9). Four out of those six herds have changing piglets origins, in detail farm 7, 13, 18 and 20. One herd is scouring from nine piglet origins per year. All farmers clean and disinfect the department after the fattening period. All herds have the salmonella and QS status one. Stabling one pig origin, but each fattening from another production source, can lead to a highly instable situation as well. The age of building does not influence the instable situation as well as the distance between the farms. The age of the buildings varies between four and 36 years. The stable size varies between 750 and 2500.

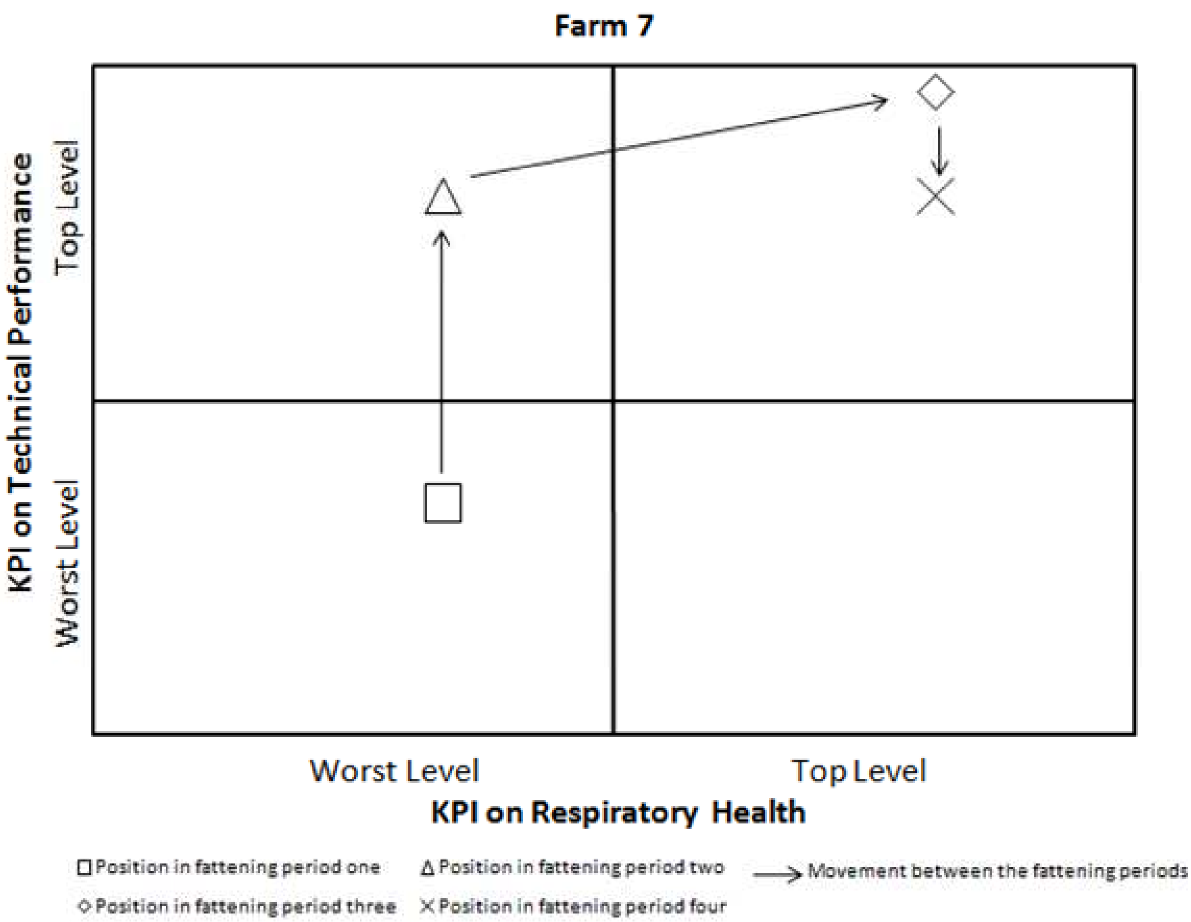

Figure 5.9 Example of highly instable farms on respiratory health and technical herd performance

Taking a view on the serological profile turns out that those farms with a stable top level position on both KPIs show a different serological profile compared to farms with stable worst level KPIs. Herd 17, one of the two optimization experts, had only in the fourth fattening periods one positive sample for PCV2 and Mhyo. In contrast farm 11, optimization newcomer, which belongs to the group with stable worst level, nearly all samples were positive in all four fattening periods. Farm seven is an example for highly instable farm. The serological profile improved over the four fattening periods. In the last period the samples were only for PRRSV and SIV. In contrast, in the first fattening period the samples were positive for PRRSV, PCV2, SIV and Mhyo. A comparable situation was observed for herd 20. In the last period, samples were positive only for PRRSV and Mhyo. In contrast, the samples were positive for all five pathogens (see details in appendix table A.2).

5.5 Discussion

The developed concept of KPI and by visualizing the farm position in a four square table enables farmers and their advisors to look for risk factors that increase the failure in respiratory heath and technical performance. Blood sampled at slaughter enables insights in the farm specific pathogen pressure and can explain the position of the farm in a four square table.

As the farms show stable position in the four square table based on two KPI, respiratory health and technical herd performance, the concept can be assessed reliable and the position of farms shows repeatability. Blood sampled at slaughter enables to explain the position in the four square table due to the pathogen pressure.

As the Pearson correlations coefficients vary between .57 and .67 and R-squares vary on a stable level and rank between .33 and .39 it can be concluded that the chosen farm level benchmark tool can be assessed as a reliable tool. Further, the positioning of farms based on the two key performance indicator leads to the conclusion that respiratory system health influences technical herd performance. This is in line with other research results focusing on ADGR and AFCR (Grest et al., 1997; Martinez et al., 2009; Martelli et al., 2009).

Non-inflections risk factors associated with respiratory system health are herd management, housing type and air quality (Paisley et al., 1993, Huey, 1996, Maes et al., 2001 and Ostanello et al., 2007). All-in-all-out hygiene policies on farm show a protective effect against pneumonia (Stärk et al., 1998). In the present study AIAO was not a guarantee for top level respiratory system health. However, farms with AIAO tend to a stable top level respiratory system health. AIAO can break the cycle of pathogen transmission (Maes et al., 2008). This is confirmed by the highly instable farms, with changing respiratory system health, applying AIAO when changing the piglet origin. This is an addition to the argumentation of Maes et al. (2008) that an AIAO production is one of the most important factors in the control of pneumonia a minimization of piglets origins is an additional important factor. A worst level position can even more be explained by a high pathogen pressure than by production parameters. Because those farms are producing in farrow-to-finish and finishing pigs from three and more piglet origins, a continuous department load without continuous cleaning and the absence of disinfection. In contrast, stable top level farms source piglets from one origin year around that suit on farm pathogen pressure, supported by an all-in-all-out per department to break the chain of infection.

A moderate or highly instable position arose through fattening pigs in an open system with continuous changing piglet origins regardless all-in-all-out per department. A less density pig region is another not negligible factor. However, it cannot be taken for granted that one piglet origin per fattening period is a success factor if in each fattening period another piglet origin is stabled, as it is indicated by moderate instable farms. In this situation cleaning and disinfection does not enable to break the infection because different age groups of pigs are still on the farm. The reduction of the frequency of animal flow within farrow-to-finish leads to a more stable overall immune status of herds (Fablet et al. 2012). The frequent purchasing of pigs from different origins and by this mingling of pigs is a risk factor for increased pneumonia, worst level of respiratory system health (Hurnik et al., 1994, Meyns et al., 2011).

However, based on the observed situation a more stable sourcing of piglets enables to reach a more continuous position in the KPI. Sourcing piglets form one origin per fattening period and changing the source in the next period may not be a successful trajectory. Herd size was not related to top or worst level of respiratory system health as Mousing et al. (1990), Elbers (1991), Hurnik et al. (1994) and Christensen and Mousing (1999) found in their studies. The herd size varied between 550 and 3500 stable places and no pattern could be found. Two farms with fattening pigs and stable with 1000 places had a top level respiratory system health with top level technical herd performance and the other extreme worst level respiratory system health and technical herd performance. Further, no evidence was found for the type of herd (finishing or farrow-to-finish) on worst or top level respiratory system. This contradicts the findings of Hurnik et al. (1994), Nielsen et al (2000) and Enøe et al. (2002).

The distance between herds, the neighborhood factor, can be determined as a factor on the position the four square table. The next farms to the optimization experts, farm 16 and 17, were more than 1.1 km far away. Therefore the findings are in line with Goodwin (1985), Stärk et al. (1992) and Nielsen et al. (2000) who analyzed distance as promoting factor of respiratory system health

In the present chapter respiratory health was only assessed on the results of the analysis of blood samples at slaughter and the percentage of pig per herd with pneumonia. However, additionally pleurisy is of major importance to determine the respiratory health. Pleurisy was not successfully detected during the official meat inspection. Therefore, it has not been included in the key performance indicator respiratory health.

If information on ADGR or AFCR was missing then the key performance indicator on technical herd performance was calculated only on one of the two performance indicators. Therefore, it could be guaranteed that each herd had assigned a key performance indicator value.

Actually, the usage of benchmarks is widely spread and many were developed for different objectives. Benchmark on gross margin per animal is widely spread. However those benchmarks do not combine technical and animal health aspects. Further, those benchmarks do not analysis factors influencing those performance results. For example, animal health aspects are missing in the LKV Bavaria benchmark systematic. Therefore, the present benchmark systematic may combine both technical and animal health related aspects.

The concept of key performance indicators supports farmers to benchmark their own performance with other farms on more than one indicator. Decision makers on farm are maybe motivated to invest more in pig herd health as it the mainly influencing the technical herd performance.

5.6 Conclusion

The formulated hypothesis, the combination of health parameters and fattening performance parameters is suitable for implementation of on farm and inter-organizational benchmarks and allows the identification of vulnerabilities, was accepted. The farm benchmark tool, based on respiratory health and technical performance, enables to compare farms. The analysis of blood sampled at slaughter gives a first explanation of the benchmark result. Different KPIs can be bundled by the applicability of two KPI on respiratory health and technical performance. Pig farms can be positioned in the four square table. Hereby, the opportunity arises to identify farms that are operating on a continuous stable top or worst level and to determine factors promoting such a situation. Consequently, decision makers are supported in their evaluation and decisions to improve the performance.

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Chapter 6 - General conclusions

6.1 Introduction

A prerequisite for profitable pig production, for food safety and for animal welfare is an optimal pig herd health status (Maes, 2013). However, the prevalence figures of lung lesions in slaughter pigs, indicating the pig health status, are comparable to those of 20 years ago (Maes, 2013). Maybe a dramatically change is hampered due to the fact that porcine respiratory disease complex is multi-factorial and subclinical. In practice, overseeing KPIs can prove expensive or difficult for organizations. The use of slaughterhouse information in monitoring systems for herd health control in pigs on farms level as well as organizational benchmark could be assessed possible approach (Düsseldorf et al, 2012). In comparison to other control points the information sources blood at slaughter has a few advantages: the potential number of blood samples that can be collected at the slaughterhouse is high, collection can be performed rather easily, the collection costs are low and farmers and their veterinarians can outsource the collection process (Elbers, 1991). Meat juice or blood can be used in four diagnostic areas, first notifiable diseases, second production diseases and third food safety related diseases and zoonoses (Blaha and Meemken, 2011). The fourth diagnostic area is non-specific marker of inflammation (Knura-Deszczka, 2000, Petersen et al., 2000, Klauke, 2012, Klauke et al., 2013). However, a broader view on the relationships between diagnostic results on production diseases, pig herd health status, technical performance and economics of production is mainly not seen by the farmers. Consequently incentives are missing to improve the current situation on pig herd health. Further, the current absence of specific and objective information about the pathogen pressure on farm will hamper the implementation of precise measures to improve pig herd health status significantly.

As in each chapter the objectives, methods and results have been discussed, the present chapter discusses general aspects and integrates all findings as well as conclusions and practical implications.

6.2 Answers to the research questions

The aim of the present research is to develop a concept of KPIs controlling consumer oriented quality and herd health management in a Bavarian pork value chain. This raises in particular the question which KPIs to use that enable specific measures to increase the pig herd health status dramatically and by doing so improving the production according to consumer oriented quality expectations.

Based on the results of the four chapters, the concept of KPIs controlling consumer oriented quality and herd health management in a Bavarian pork chain was developed and consists of four elements:

1) Regional defined pathogen pattern focused on PRDC on which blood sampled at slaughter is analyzed
2) Serological indicator and farm specific serological profile to benchmark and to determine the most influential pathogens on KPIs on farm and for the region
3) Organizational merging of data in a two dimensional benchmark of animal health and technical performance
4) Interpretation guide through the enzootic risk matrix

Based on the four chapters described in this research, the following can be concluded:

- The developed three shells continuous improvement model is a valuable tool for guiding through different consumer oriented and herd health management tasks in the pork production.
- The information gained on farm pathogen pressure through analyzing blood sampled at slaughter enables the development of a concept of KPIs.
- Based on the individual ELISA serology results, a SI was developed enabling a benchmark of farms according to the pathogen pressure.
- The developed SI explains exactly which safe decisions to take in order to increase the performance dramatically.
- The SI enables the chain actors, such as the farmer and his or her veterinarian to make safer decisions on pig herd health management.

- The SI enables the net chain coordinator to compare farms on two KPIs, respiratory health and technical performance. Farmers can be compared with other farmers.
- The SI can be described as independent KPI and enables the chain actors to explain the value of other KPIs

The formulated hypotheses were tested and can be answered as follows.

Hypothesis 1: The value of information for monitoring and testing strategies to promote the continuous improvement process can be explained by the combination of quality tools, processes and tasks in a three shell continuous improvement process model. (Chapter 2)

The application of the combination of the three shells continuous improvement model with the score-model to estimate the information value enabled to identify an information source point, such as the slaughterhouse, to answer by the industry and the society formulated questions. The combination of a central process with tasks and tools supported through formulated questions leads to a convenient usage for managers.

Hypothesis 2: A monitoring and testing strategy based on blood sampled at slaughter is suitable for interpretation on key performance indicators. (Chapter 3)

Based on the ELISA serology results, a SI was calculated (the average proportion of positive samples). The SI varied between zero and 1. In four out four fattening periods the SI is significant correlated with the percentage of pigs with pneumonia per delivery (1: $p < .0001$, 2: $p < .01$, 3: $p < .05$, 4: $p < .01$). In two out four fattening periods the SI is significant correlated with averaged daily growth rate (1: $p < .05$, 2: $p < .01$) and average feed conversion rate (1: $p < .05$, 2: $p < .05$). In three out of four fattening periods the presence of APP 2 and SIV mostly influences the ratio of pigs with pneumonia per herd. In two out of four fattening periods PRRSV is the most influential pathogen on average daily growth rate and average feed conversion rate. APP 2 is the most influential pathogen on clinic symptoms of PRDC. Further, the SI and the percentage of pneumonia per herd are good indicators for pig herd respiratory health status, as the herds with a lower SI ($p<.01$) and a lower percentage of pneumonia ($p<.01$) used fewer antibiotics for respiratory disease.

Hypothesis 3: The monitoring and testing strategy enables to explain the financial impact of production diseases on farm level and that *the benefits of this strategy outweigh the costs. (Chapter 4)*

The gross margin per stable place varies between 17.90 € and 119.51 €. The SI and the gross margin per stable place are significant correlated in the first fattening period -.584 ($p < .01$) and the second fattening period -.656 ($p < .01$). A SI of one halved the gross margin per stable place in both scenarios. PRRSV was in two out for fattening periods the most relevant pathogen on the gross margin per stable place.

The break even of the monitoring service and prevention costs such as vaccination of piglets is minimum 115 and maximum 766 bought piglets per year. Break even in ordering highly qualitative piglets is minimum 77 and maximum 230 bought piglets per year.

Hypothesis 4: The combination of health parameters and fattening performance parameters is suitable for implementation of on farm and inter-organizational benchmarks and allows the identification of vulnerabilities. (Chapter 5)

The positioning of farms in the four square table, on the x-axis KPI on respiratory health and on the y-axis KPI on technical performance, showed over the four fattening periods clearly differences between the farms. Five farms had a stable position over the four periods. Those farms are stable located in one quadrate. Three of five can be characterized as optimization newcomer and two as optimization experts. Nine out of the 20 farms showed an instable position. Those farms changed their position over two quadrates. Six out of 20 farms showed a highly instable position. Those farms were positioned in three out of four quadrates. None of the farms were positioned on four quadrates.

The risk of changing performance on KPI on technical performance and KPI on respiratory system, consequently an instable position, arose through fattening pigs in open system with continuous changing piglet origins regardless all-in-all-out per department. Risk factors supporting a continuous worst level KPI on technical performance and respiratory health the production systems farrow-to-finish as well as fattening pigs from three and more piglet origins, continuous departments load without continuous cleaning and the absence of disinfection. Additionally, a high pathogen pressure is caused though this management. A success factor for top level KPI on technical performance and KPI on respiratory health is a stable sourcing of piglets from one origin year around. Further the piglet health should suit the on farm pathogen pressure, supported by an all-in-all-out per department to break the chain of infection. A less density pig region is another not negligible factor. However, it cannot be taken for granted that one piglet origin per fattening period is a success factor if in each fattening period another piglet origin is stabled. In this situation cleaning and disinfection do not avoid infection because different age groups of pigs are still on the farm.

6.3 Managerial implications

The three shells continuous improvement model leads to the identification of an added value information source, blood at slaughter. Blood sampled at slaughter is a reliable information source for controlling different KPIs. Implementing a monitoring of production diseases based on blood sampled showed an early break even between costs and benefits.

A number of specific managerial implications can be made concerning the pork production in Bavaria:

- Pig producers and their veterinarians should use the additional information gained through analyzing blood sampled at slaughter on pathogens causing PRDC problems. Without the detailed information specific measures are hampered on the farm to promote the continuous improvement process on the KPIs.
- The SI enables inter-organizational benchmarks, i.e. between fattening periods or seasons, and intra-organizational benchmarks, i.e. between farms or regions.
- Farm veterinarians should use the information on pathogens to derive efficient decisions on treatment and vaccination strategies.
- The serological results must always be seen in the context of clinical symptoms, percentage of pigs with pneumonia and farm-specific characteristics to derive the most efficient measure.
- Pig slaughter companies should increase the possibility to sample blood at slaughter for suppliers to enable an expansion of the implemented concept of KPIs.
- The merging of information about the health status of piglets from the TIGA database and the identified pathogen pressure through analyzing blood sampled at slaughter

would lead to an even better matching of farms, piglet producers and fatteners. A better matching on the health status could lead to an improvement of the KPIs.

- The new developed KPI, serological indicator, enables to benchmark farms according to their pathogen pressure. This is a unique chance to understand even better the gap between best class and worst class farms.
- The pathogen pattern on which blood sampled at the inspection point slaughterhouse can easily be extended. The organization effort for the net-chain coordinator and the farmer as well as the farm veterinarian will stay the same. The analysis of blood sampled at slaughter supports the FMEA of technical performance and animal health.
- The laboratory results can be shown in a statistic process control chart. The analysis of blood sampled at slaughter is a convenient solution to explain the performance of different KPIs along the pork value chain

6.4 Further research

This research resulted in different topics for further research. This section describes the three areas of further research.

1) Assessing the contribution of information gained through blood sampled at slaughter on the key performance indicators

This research shows the results of a state of the art analysis. Correlations between SI were investigated based on blood sampled at slaughter and pig herd health status as well as technical performance and usage of antibiotics. Further research is needed to assess the effect of the usage of those detailed information on pathogens causing PRDC problems on farm regarding the continuous improvement process on pig herd health, technical herd performance and usage of antimicrobial drugs in pork production. Therefore, a validation study with a larger set of farms is recommended by the researcher.

2) Extending the analysis of blood sampled at slaughter to additional pathogens

In this research blood sampled at slaughter was analyzed on antibodies of pathogens associated with the PRDC and based on this the SI was developed. Further research is needed to assess the potential of blood at slaughter for other production diseases such as gastrointestinal disorder.

3) Validation of the four square table on key performance indicators

The concept of the four square table to plot farms on respiratory health and technical performance should be validated with another set of farms. As only the respiratory system health was brought in correlation with the technical herd performance an extension on other production diseases should be performed.

4) Usage of antibiotics and key performance indicators

In the first fattening period significant correlation between usage of antibiotics and percentage of pigs with pneumonia as well as SI was found. Unfortunately this could not be validated in the other three investigated fattening periods. Therefore, a validation in another research project might help to clarify the correlation.

5) Seasonal influence on the results

Since the SI was significant correlated with the daily growth rate, feed conversion rate and gross margin per stable in the first two periods and not in the two, these were the winter fattening periods, it should be investigated whether this was a coincidence.

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8 List of figures

9 Appendix

Chapter 3

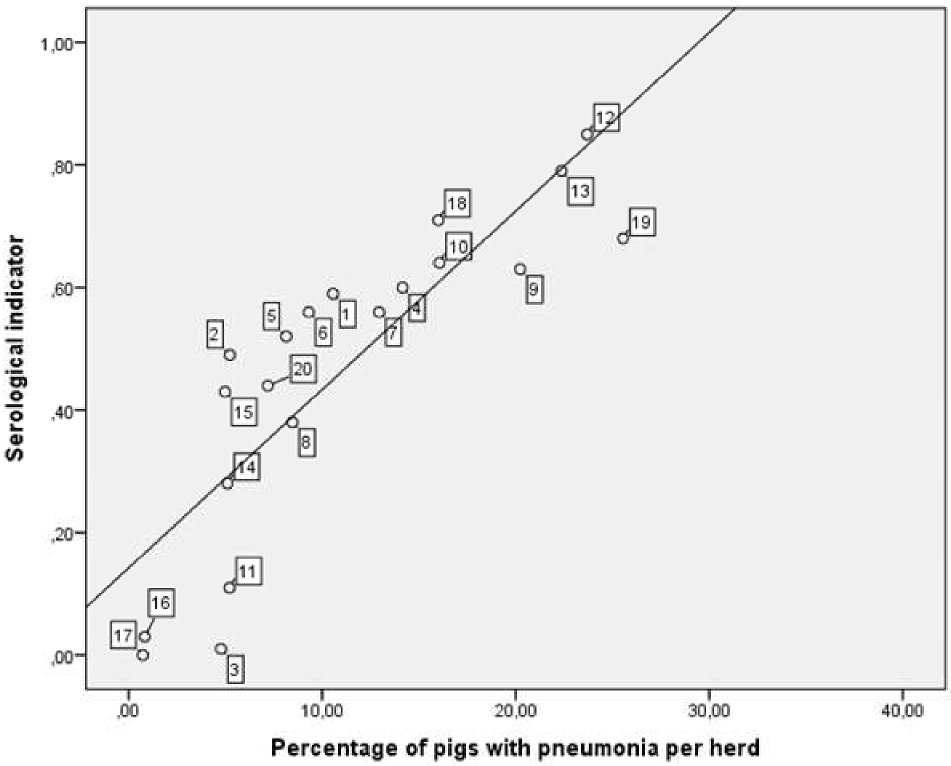

Figure A.1 Serological indicator in relation to percentage of pigs with pneumonia per individual herd in fattening period one

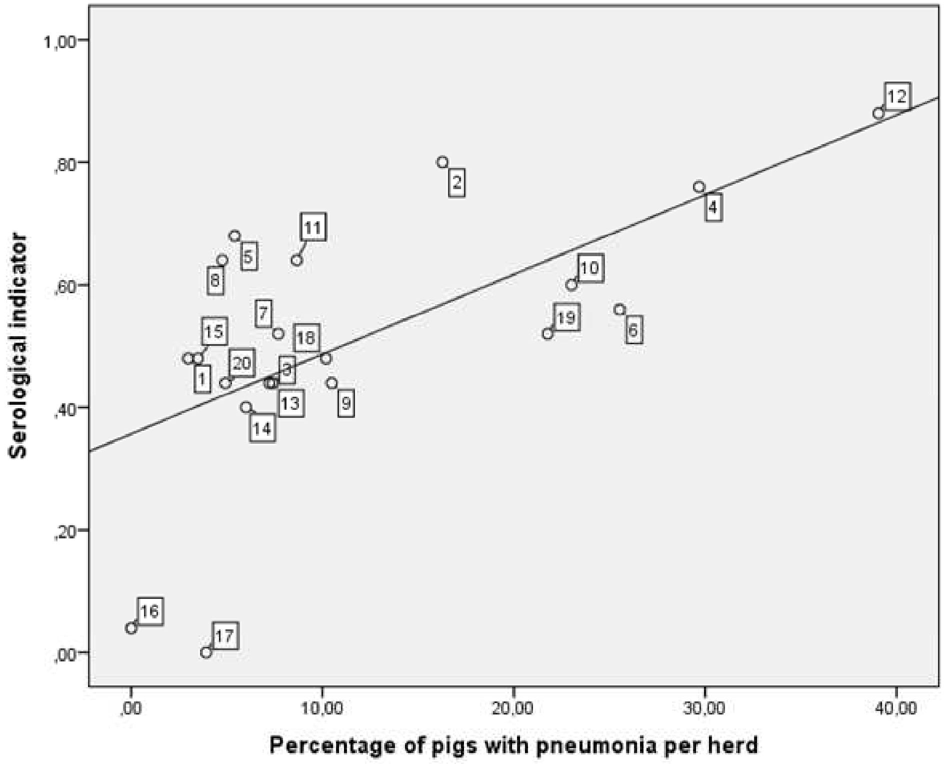

Figure A.2 Serological indicator in relation to percentage of pigs with pneumonia per individual herd in fattening period two

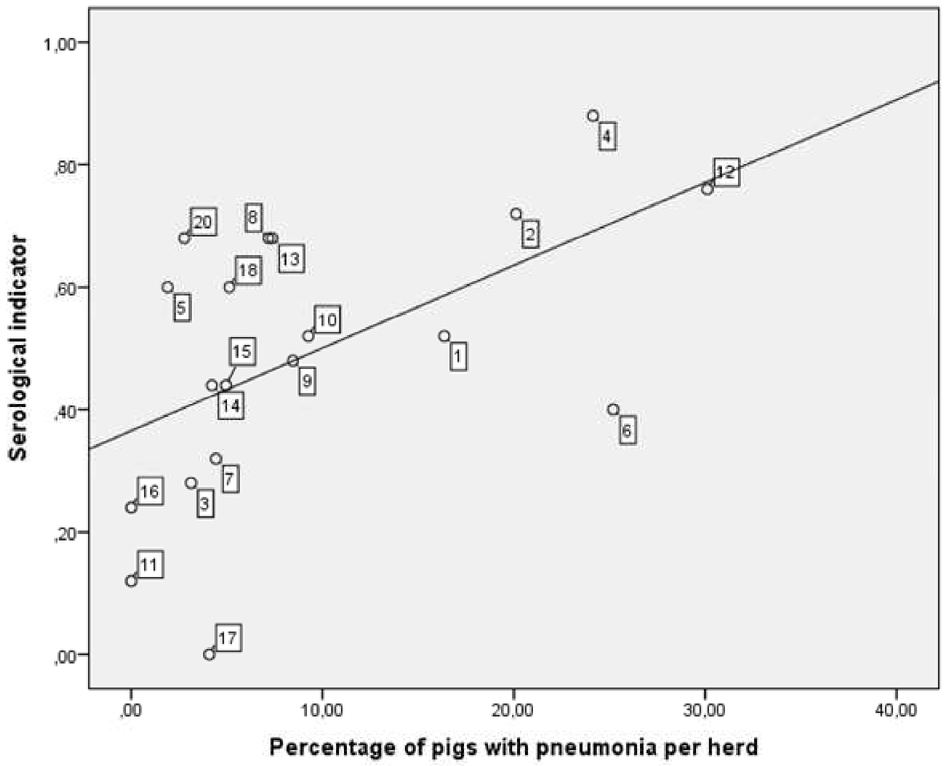

Figure A.3 Serological indicator in relation to percentage of pigs with pneumonia per individual herd in fattening period three

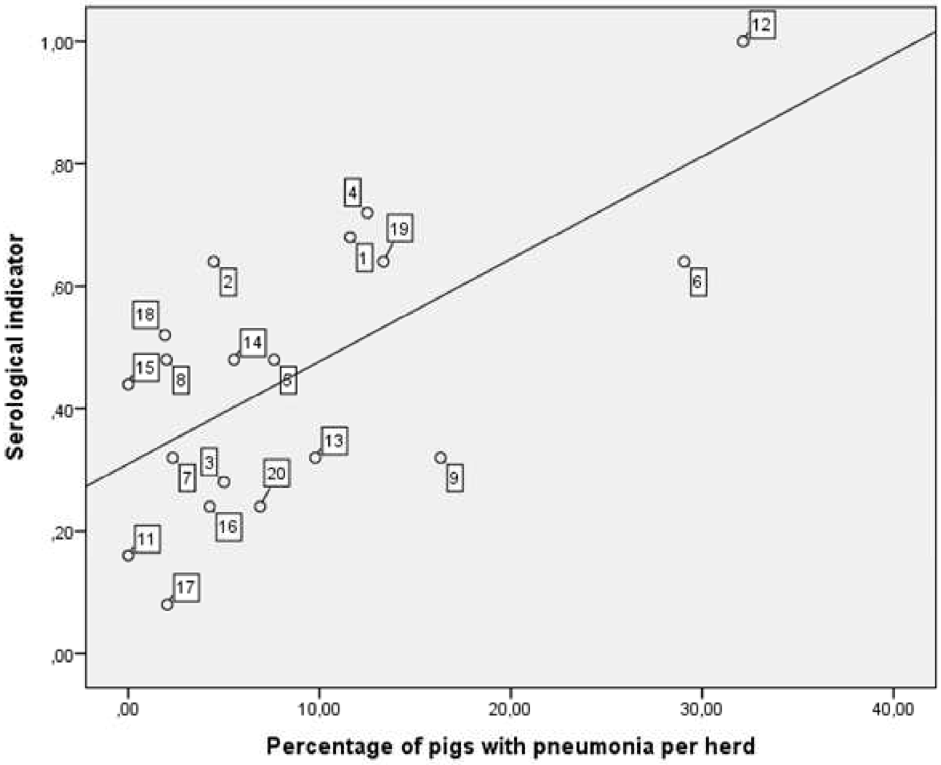

Figure A.4 Serological indicator in relation to percentage of pigs with pneumonia per individual herd in fattening period four

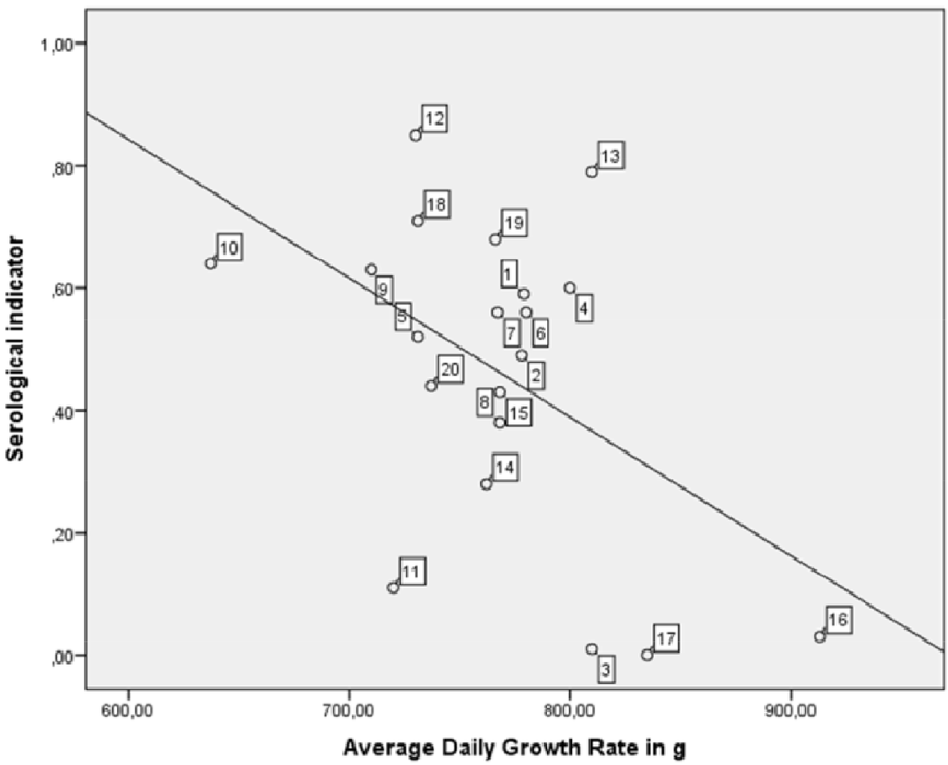

Figure A.5 Serological indicator in relation to average daily growth rate per individual herd in fattening period one

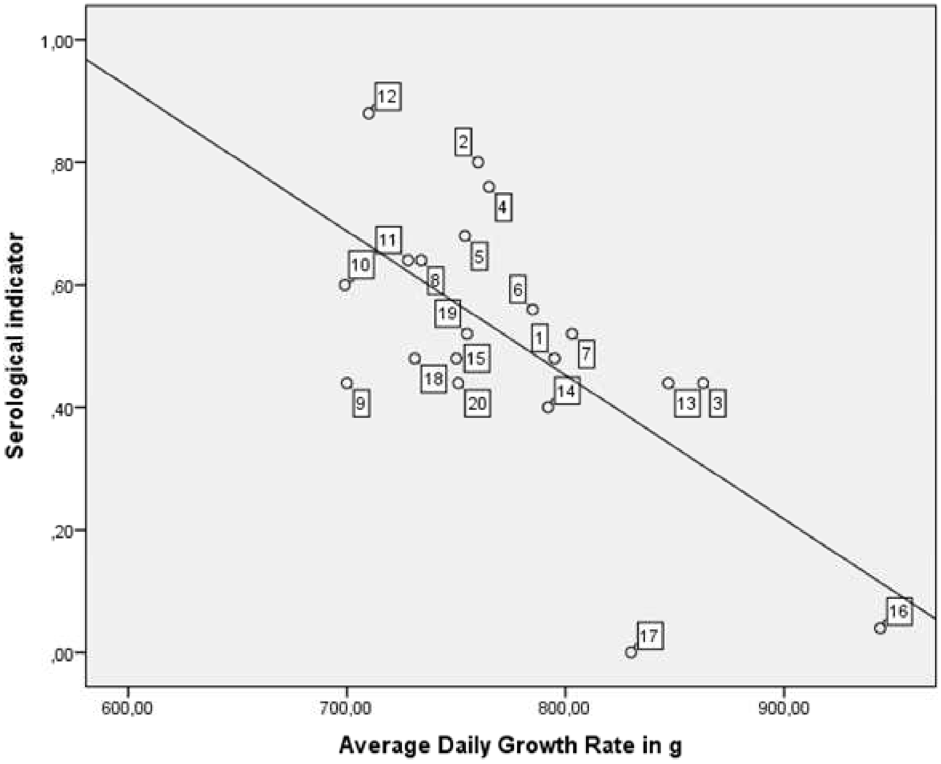

Figure A.6 Serological indicator in relation to average daily growth rate per individual herd in fattening period two

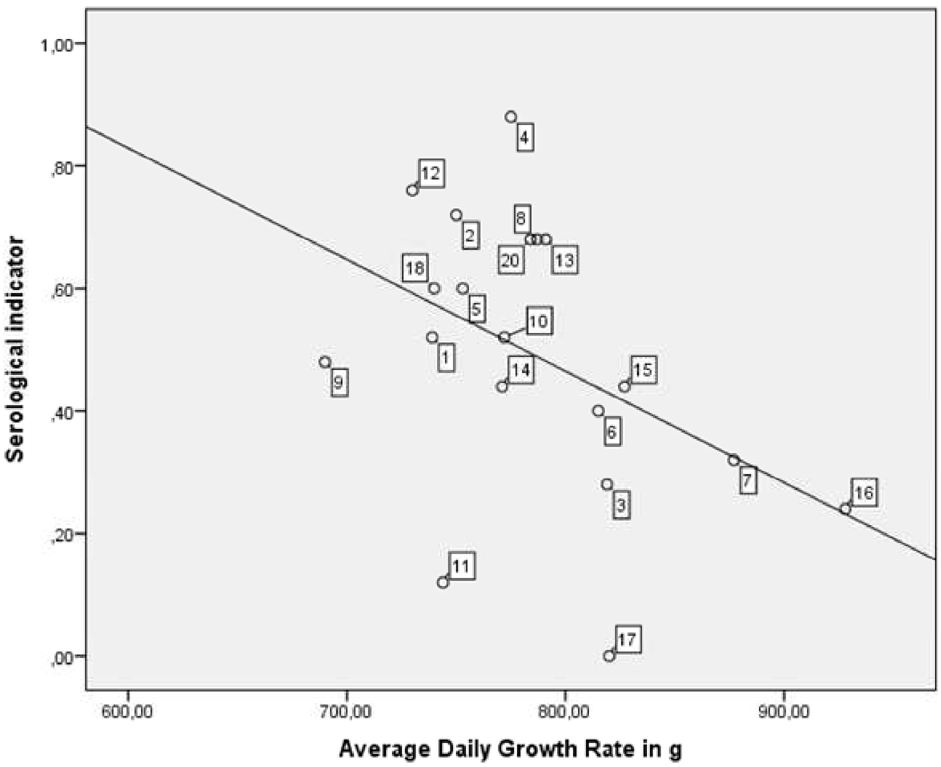

Figure A.7 Serological indicator in relation to average daily growth rate per individual herd in fattening period three

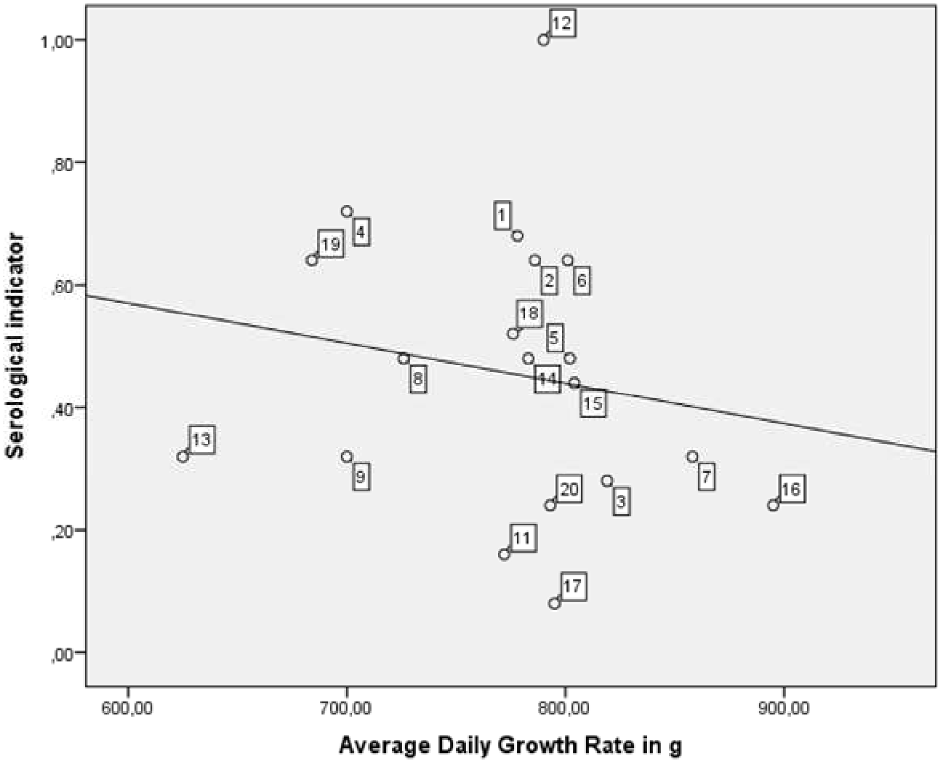

Figure A.8 Serological indicator in relation to average daily growth rate per individual herd in fattening period four

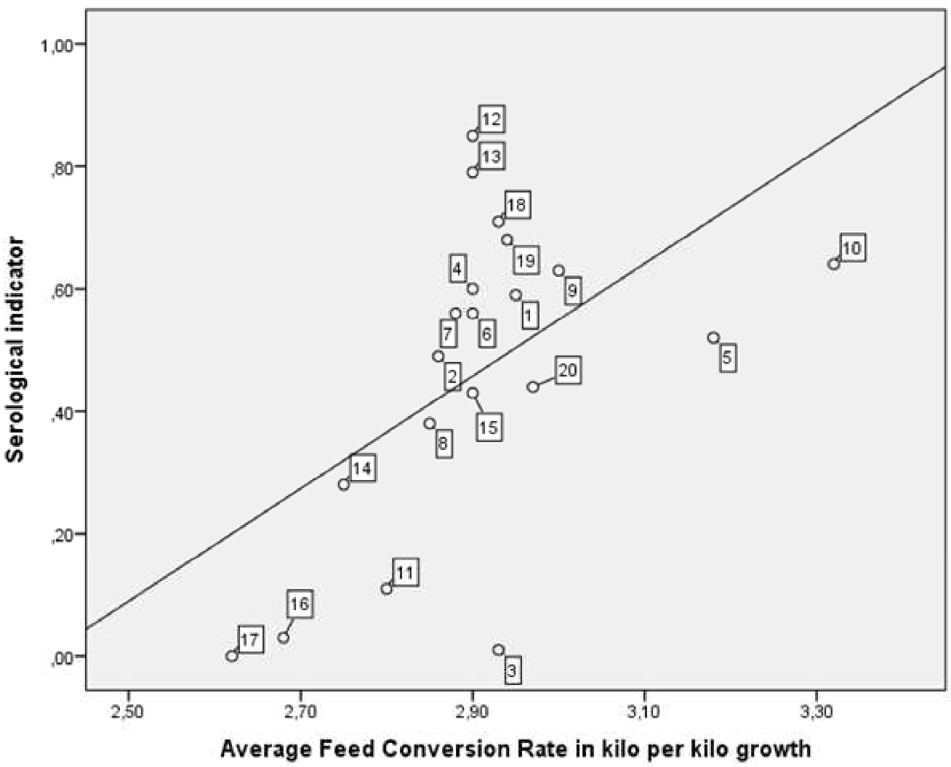

Figure A.9 Serological indicator in relation to average feed conversion rate per individual herd in fattening period one

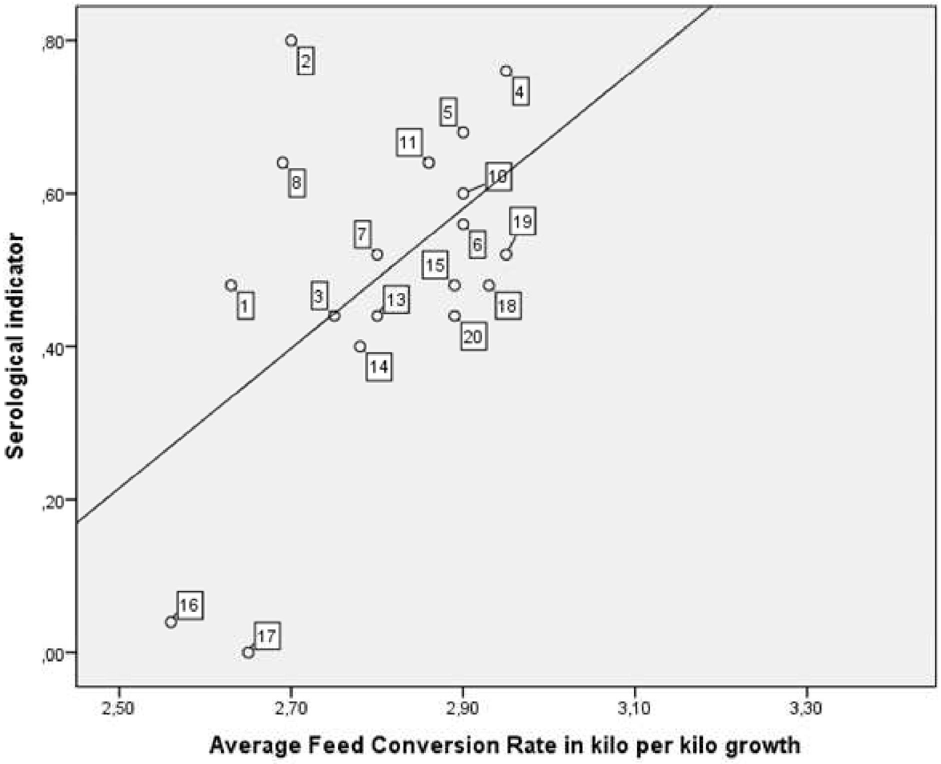

Figure A.10 Serological indicator in relation to average feed conversion rate per individual herd in fattening period two

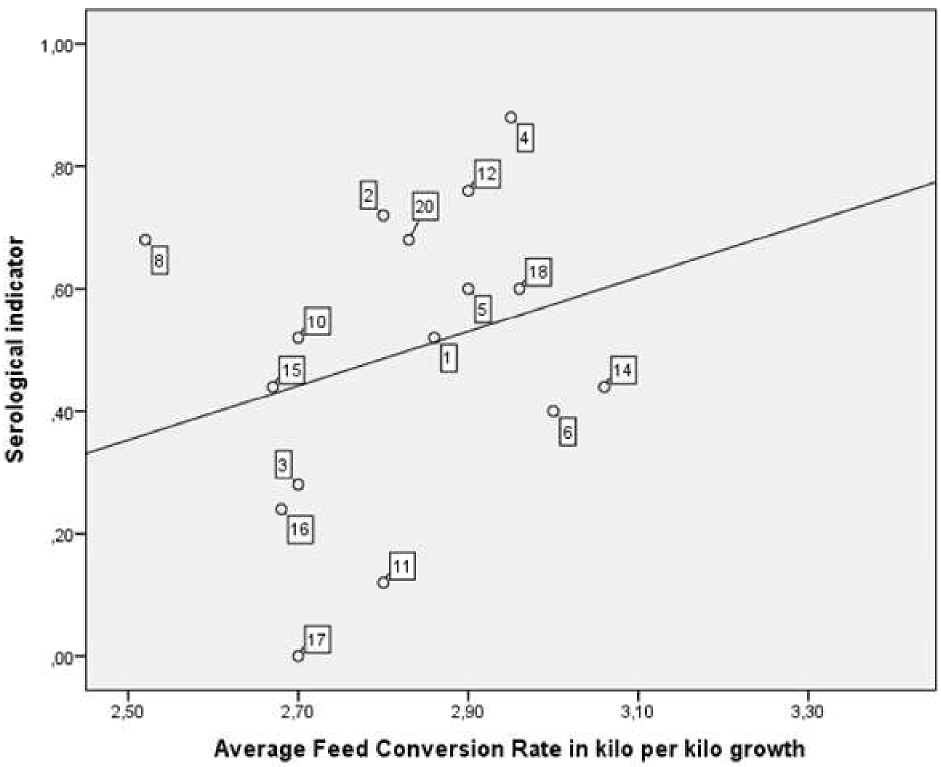

Figure A.11 Serological indicator in relation to average feed conversion rate per individual herd in fattening period three

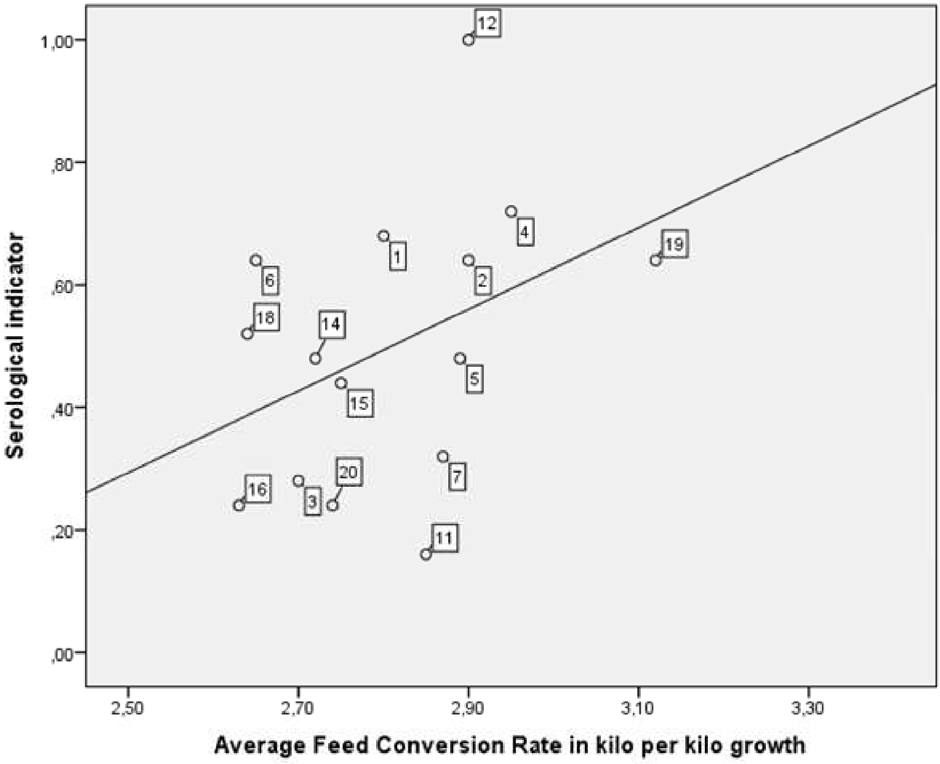

Figure A.12 Serological indicator in relation to average feed conversion rate per individual herd in fattening period four

Table A.1 Detailed statistical analysis between serological indicator and percentage of pneumonia per herd for herds with and without antimicrobial usage of drugs

Parameter	Antibiotics used	Mean	Median	Standard Deviation	Minimum	Maximum
Serological Indicator	Yes	0.55	0.58	0.19	0.11	0.85
	No	0.12	0.02	0.20	0.00	0.43
Percentage of pneumonia per herd	Yes	13.21	11.74	6.83	5.11	25.55
	No	2.82	2.80	2.36	0.73	4.97

Chapter 4

KWIN 2010			HUIDIG		
Vleesvarkens	KWIN				
verkoop vleesvarken	97,2	kg	€ 1,820	€	176,96
aankoop big	1		€ 60,000	€	60,00
transport	1		€ 1,000	€	1,00
voer					
startvoer	0	kg	€ -	€	-
tussenvoer	0	kg	€ -	€	-
afmestvoer	284	kg	€ 0,320	€	91,02
uitval	0,00%		€ 65,000	€	-
Voerwinst per afgeleverd vleesvarken				€	24,94
Voerwinst per aanwezig varken				€	73,16
Rondes per jaar			2,93		
Groei /dag	800	g/d			
Opleggewicht	25,0	kg			
Voederconversie	2,86				
Voerkosten per kg groei	0,915				
Aantal aanwezige plaatsen					2.400
Aantal gemiddeld aanwezig vleesvarkens					2.400
Aantal afgeleverde vleesvarkens					7.040
Bezetting %					100%
TOTALE voerwinst				€	175.573

VOERWINST BENADERING			Alternatief: BEREN		
Vleesvarkens	KWIN				
verkoop vleesvarken	97,2	kg	€ 1,820	€	176,90
aankoop biggen	1		€ 60,000	€	60,00
tranport	1		€ 1,000	€	1,00
voer					
startvoer	0	kg		€	-
tussenvoer	0	kg	€ -	€	-
afmestvoer	296	kg	€ 0,320	€	94,80
uitval	0,00%		€ 65,000	€	-
Voerwinst per afgeleverd vleesvarken				€	21,10
voerwinst per aanwezig varkens				€	58,11
Rondes per jaar			2,75		
Groei /dag	750	g/d			
Opleggewicht	25,0	kg			
Voederconversie	2,98				
Voerkosten per kg groe	0,954				
Aantal aanwezige plaatsen					2.400
Aantal gemiddeld aanwezig vleesvarkens					2.400
Aantal afgeleverde vleesvarkens					6.609
Bezetting %					100%
TOTALE voerwinst				€	139.457
VOORDEEL / NADEEL voerwinst				€	36.116-

Samenvatting				
	huidig	alternatief		verschil
Groei	800	750		-50
Uitval	0,00%	0,0%		0,00%
Biggenprijs	60	60	€	-
Opbrengsprijs	1,82	1,82	€	-
Bezettingsgraad	100%	100%		0,00%

Figure A.13 Screenshot of the model of ABAB Consultants B.V. to calculate the financial ratios.

Chapter 5

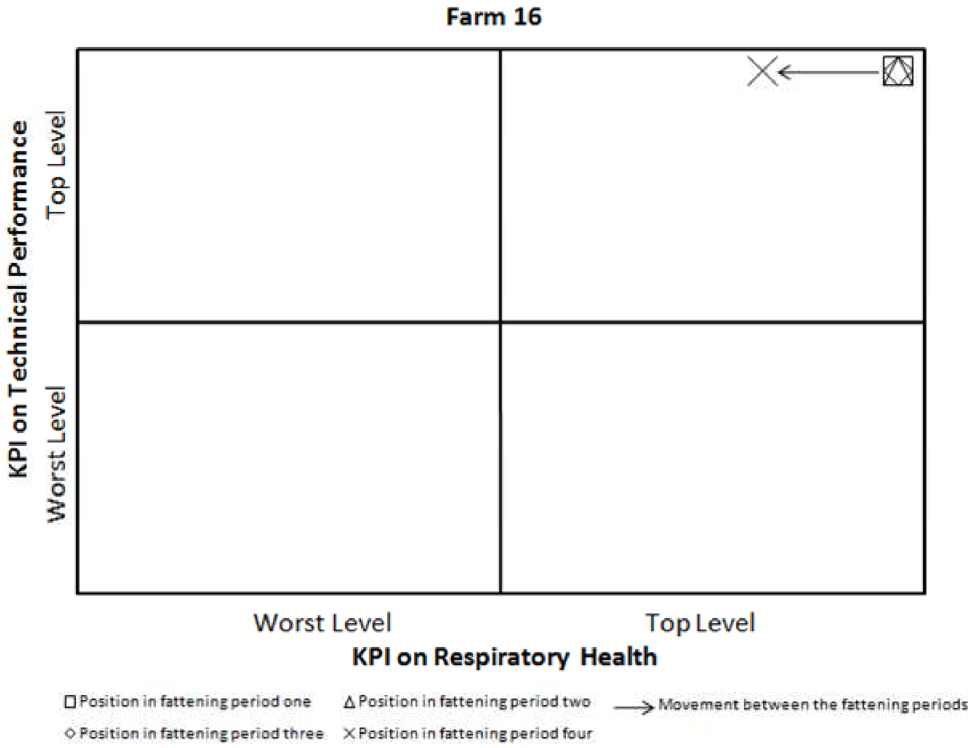

Figure A.14 Stable top level respiratory health and technical performance farm 16

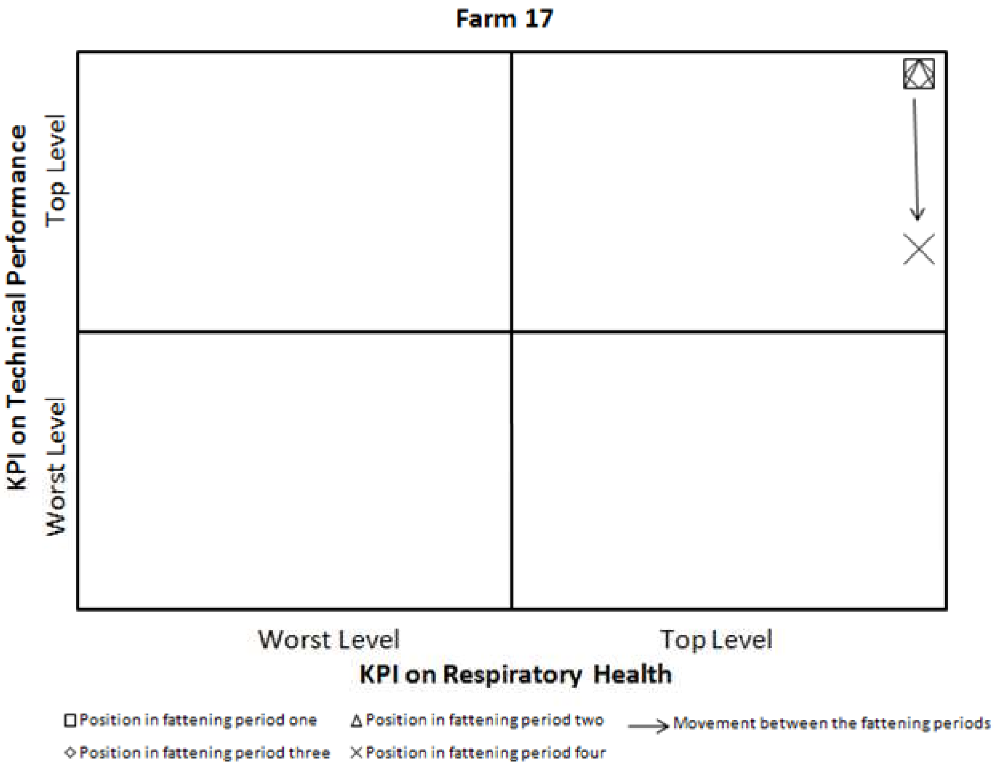

Figure A.15 Stable top level respiratory health and technical performance farm 17

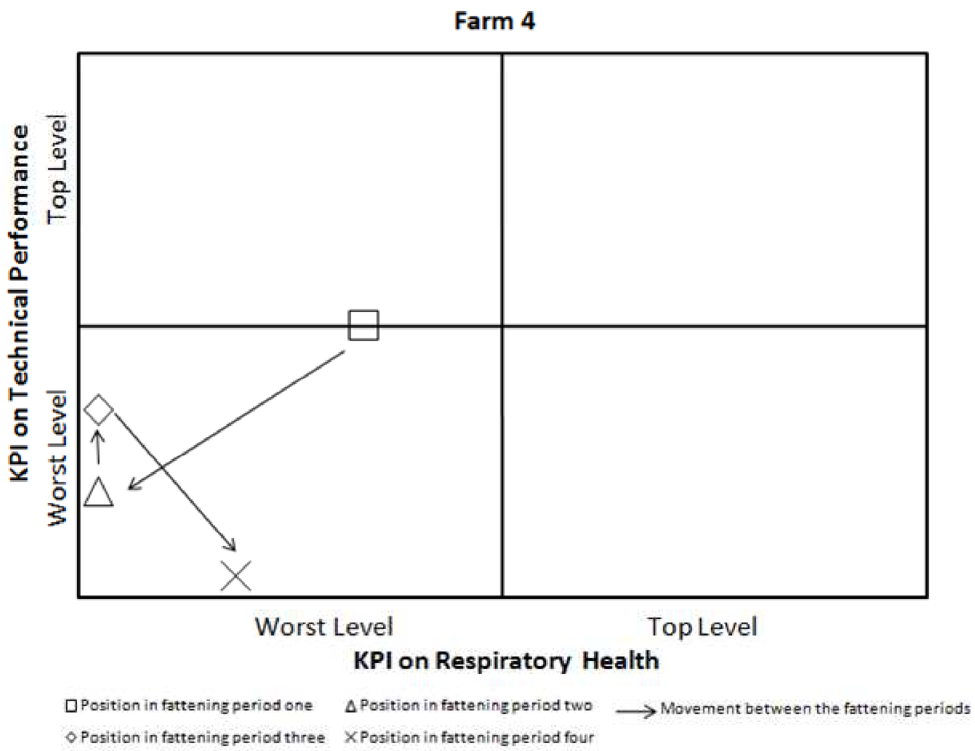

Figure A.16 Stable worst level respiratory health and technical performance farm 4

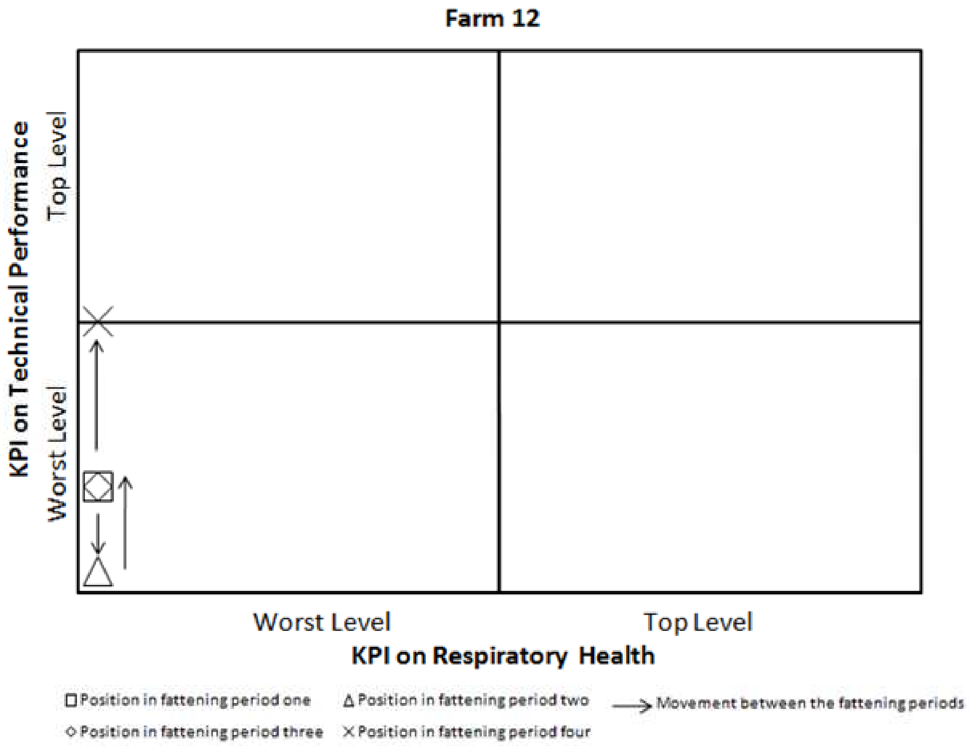

Figure A.17 Stable worst level respiratory health and technical performance farm 12

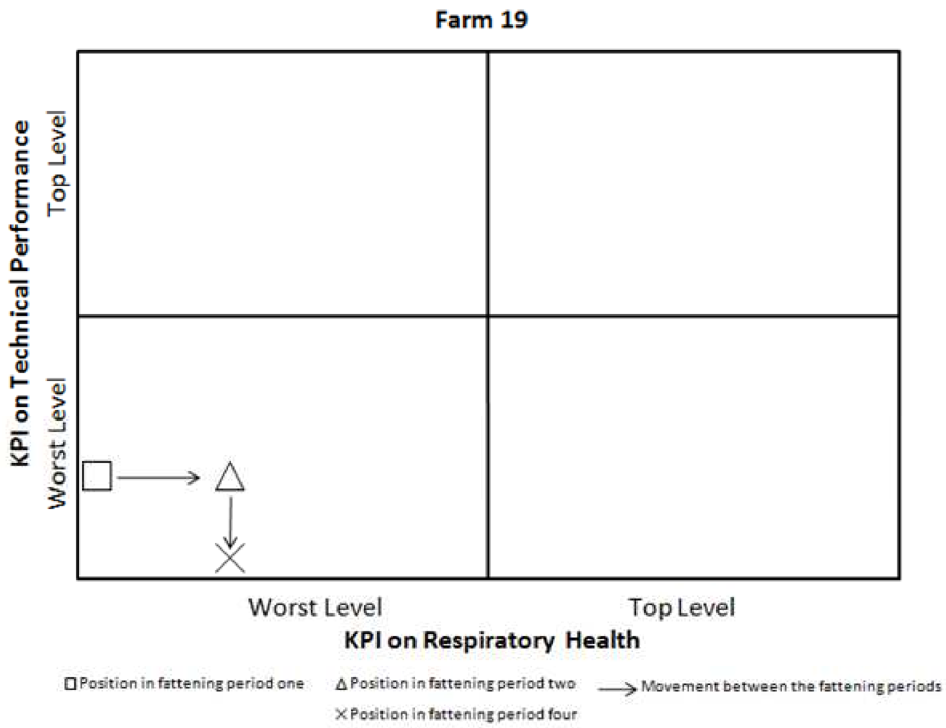

Figure A.18 Stable worst level respiratory health and technical performance farm 19

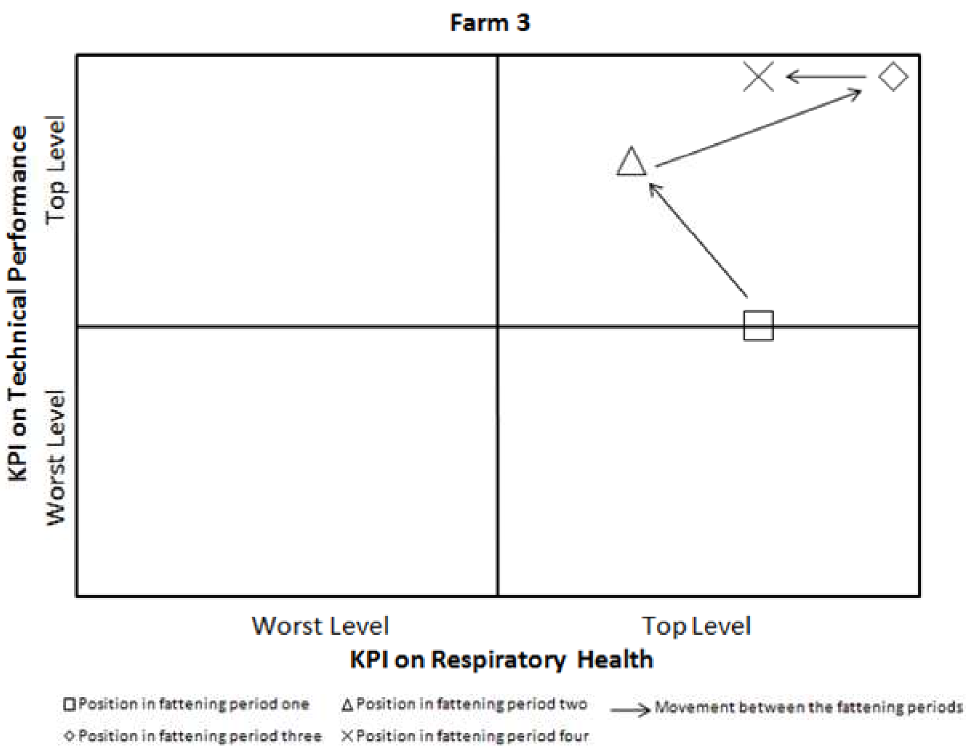

Figure A.19 Stable top level respiratory health and changing technical performance farm 3

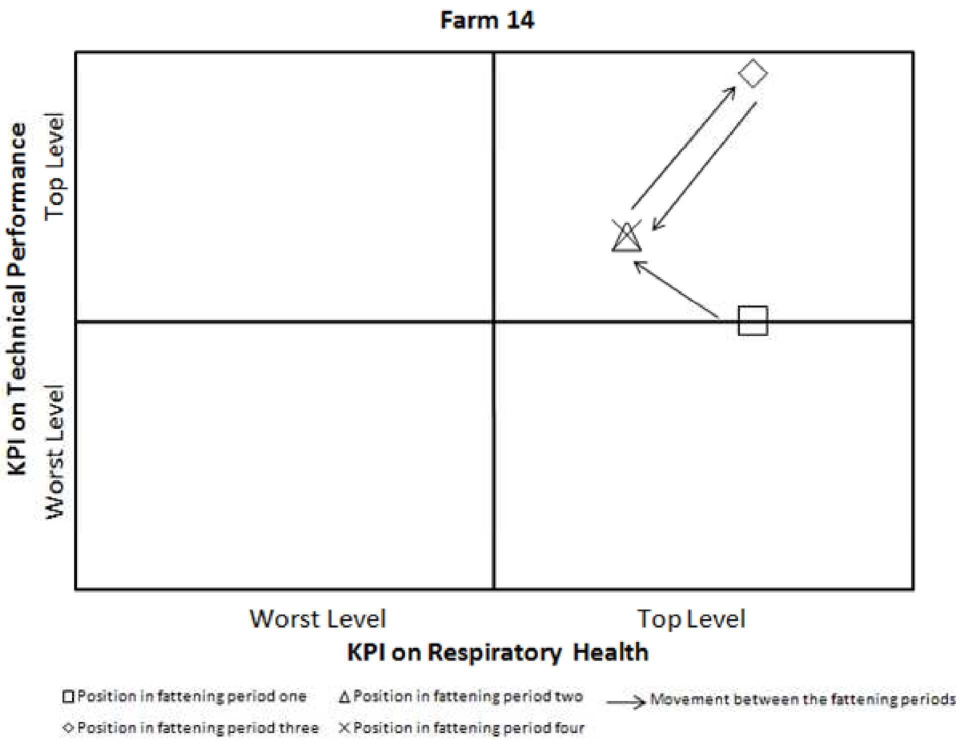

Figure A.20 Stable top level respiratory health and changing technical performance farm 14

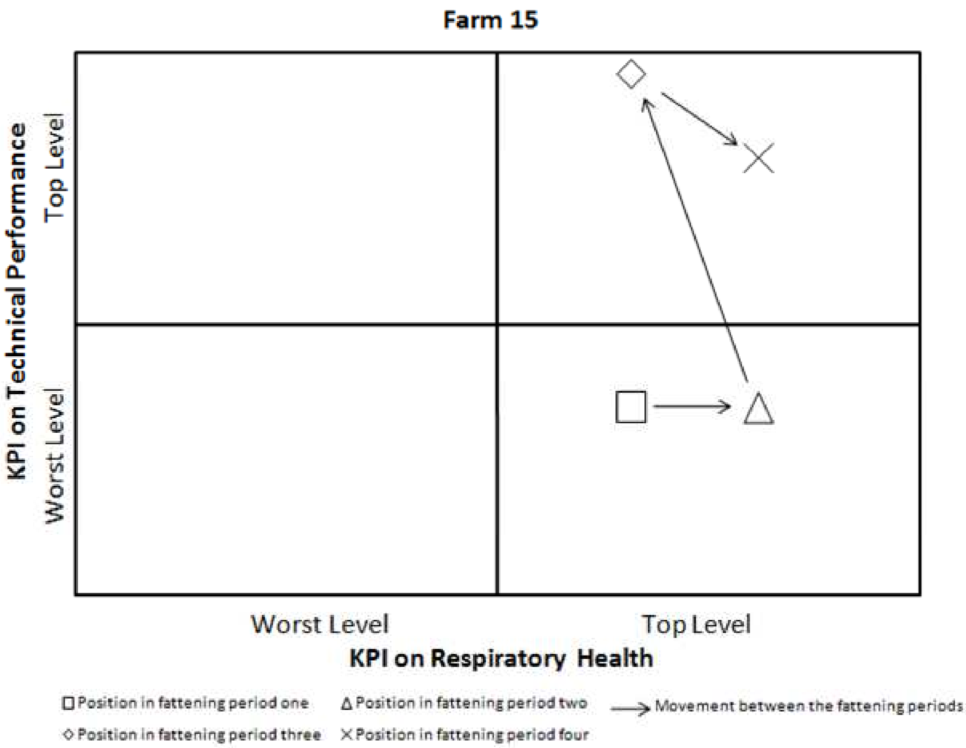

Figure A.21 Stable top level respiratory health and changing technical performance farm 15

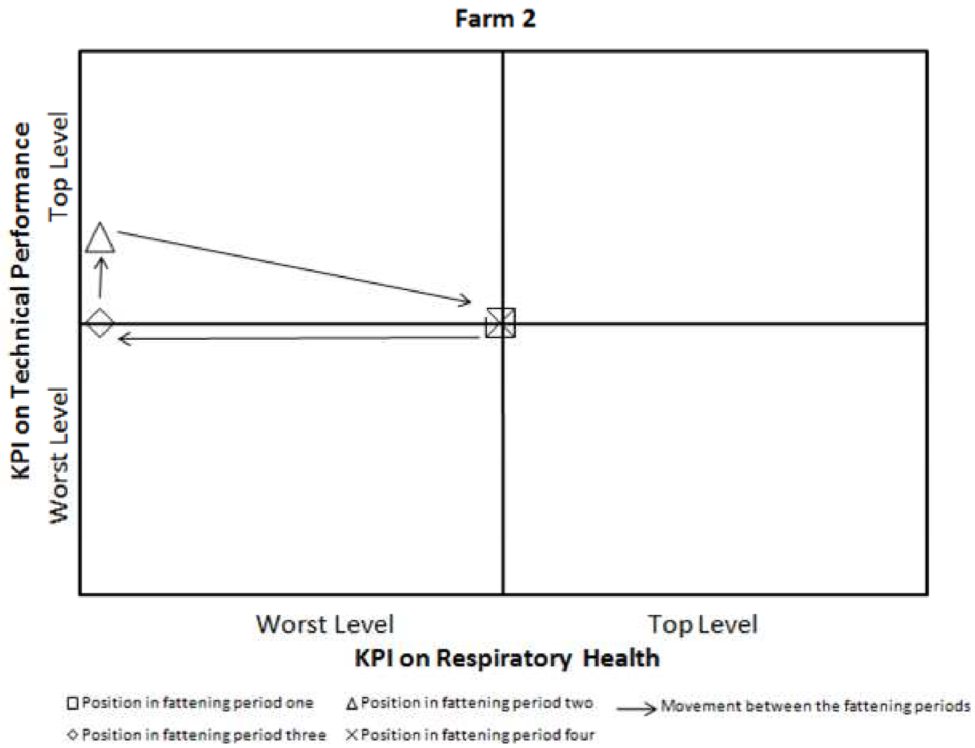

Figure A.22 Stable worst level respiratory health and changing technical performance farm 2

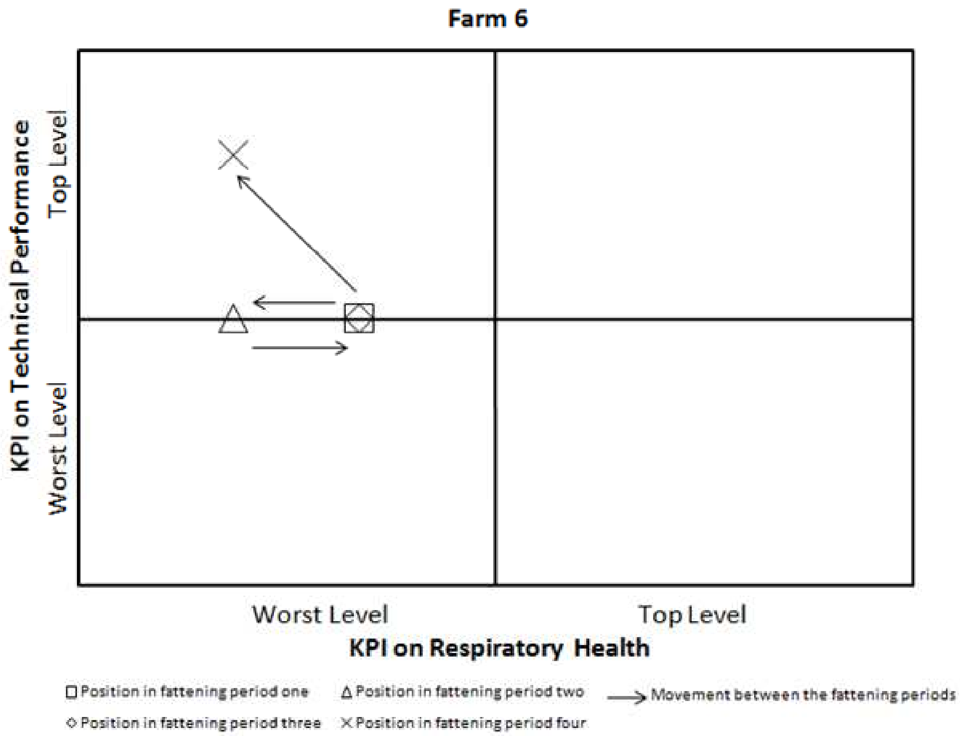

Figure A.23 Stable worst level respiratory health and changing technical performance farm 6

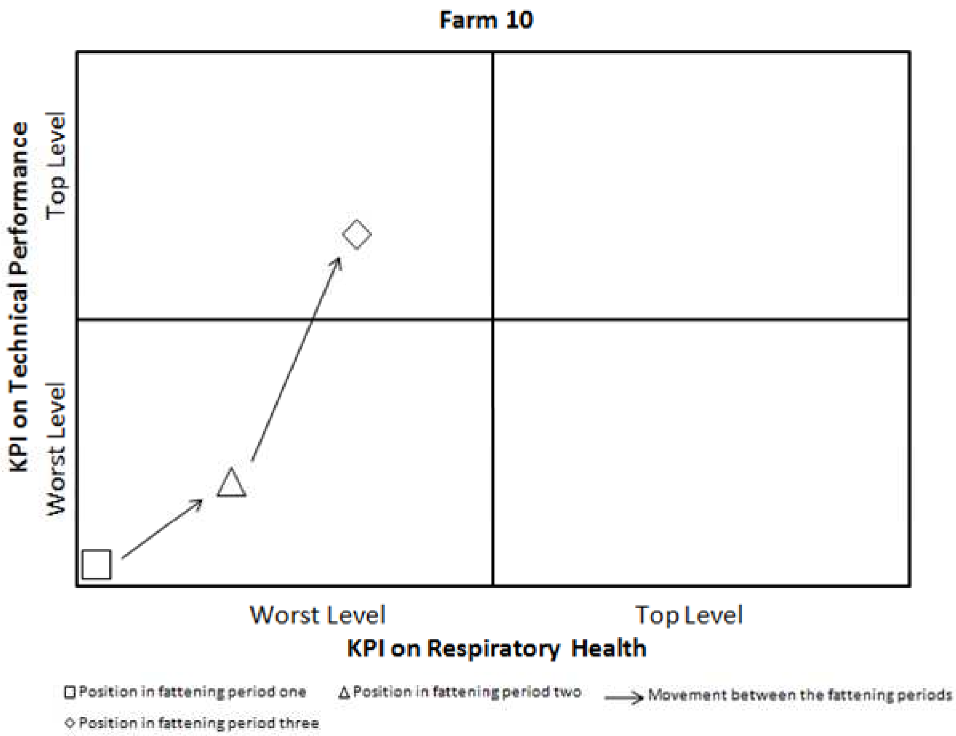

Figure A.24 Stable worst level respiratory health and changing technical performance farm 10

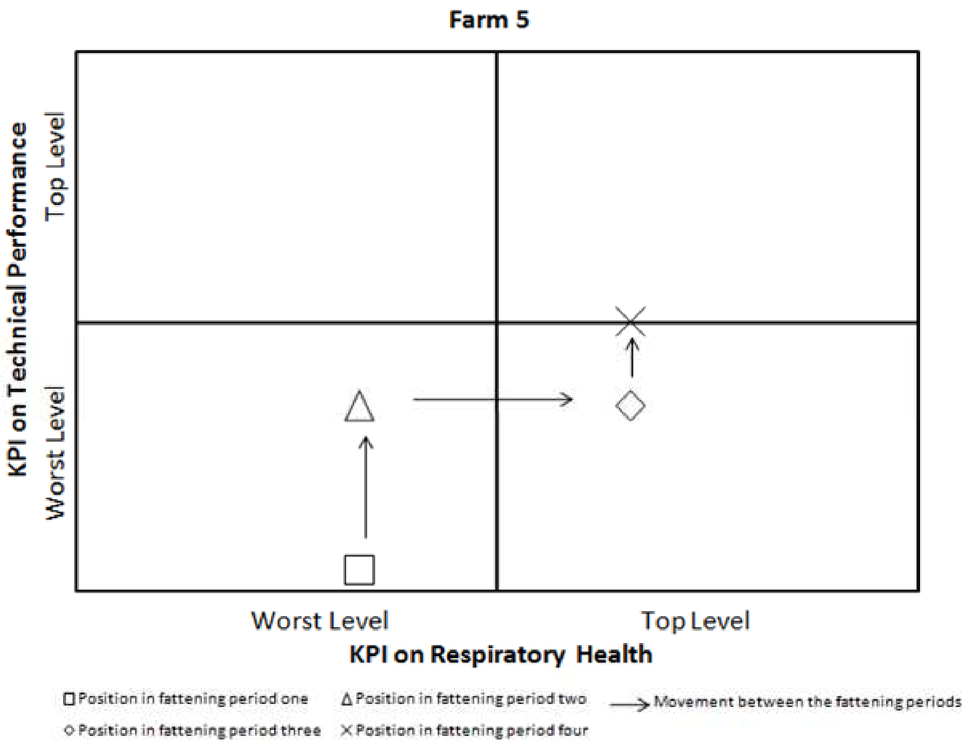

Figure A.25 Stable worst level technical performance and changing respiratory health farm 5

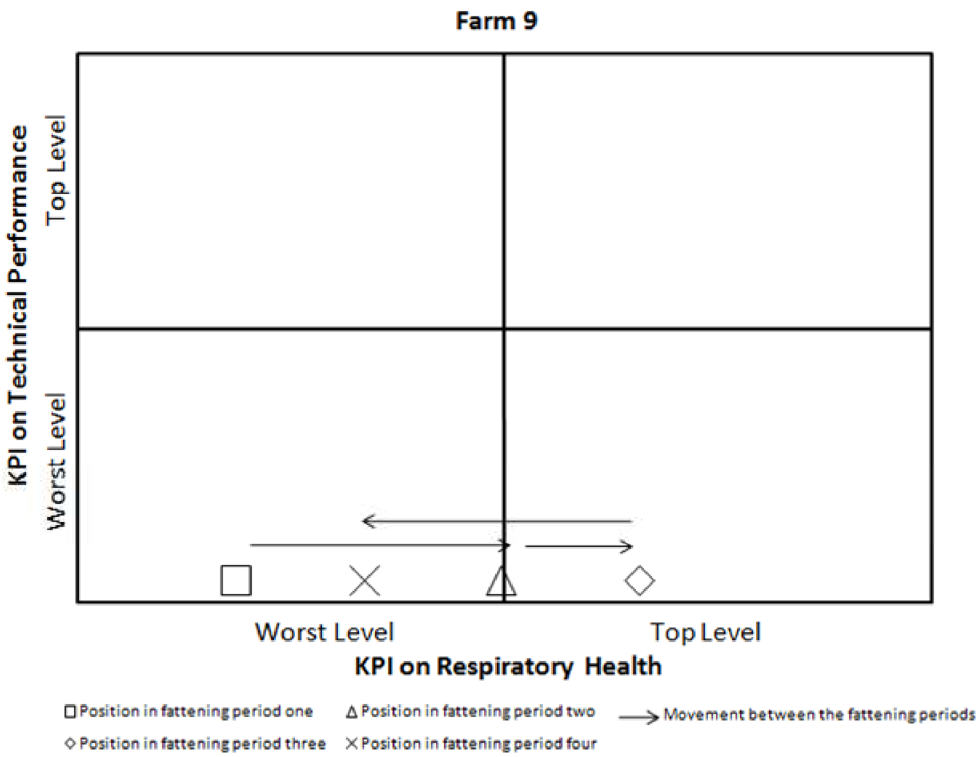

Figure A.26 Stable worst level technical performance and changing respiratory health farm 9

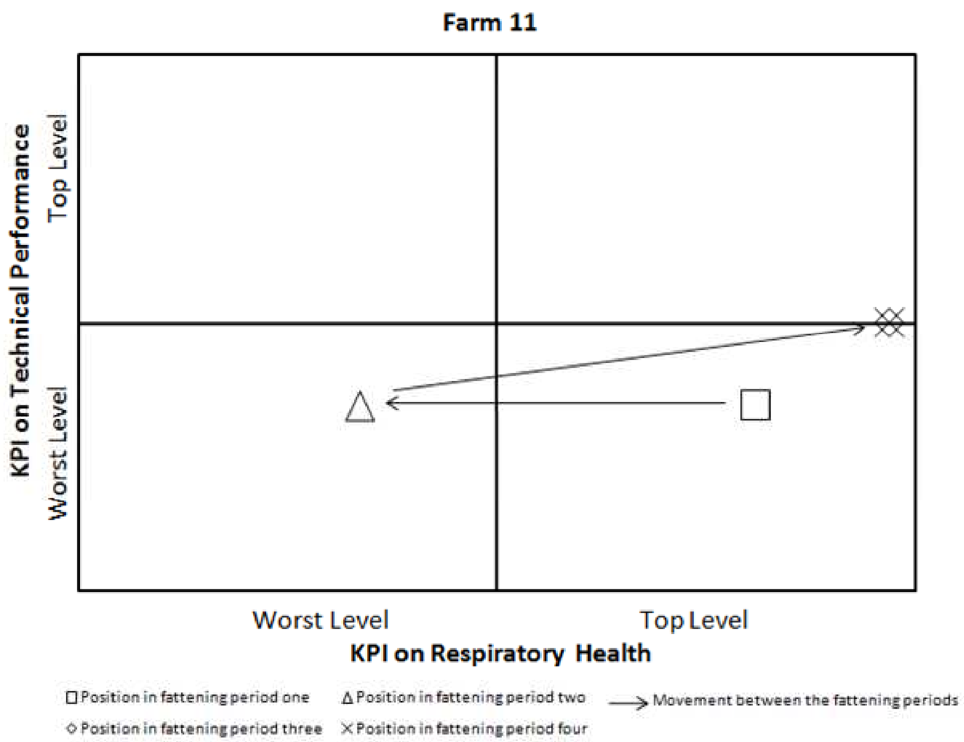

Figure A.27 Stable worst level technical performance and changing respiratory health farm 11

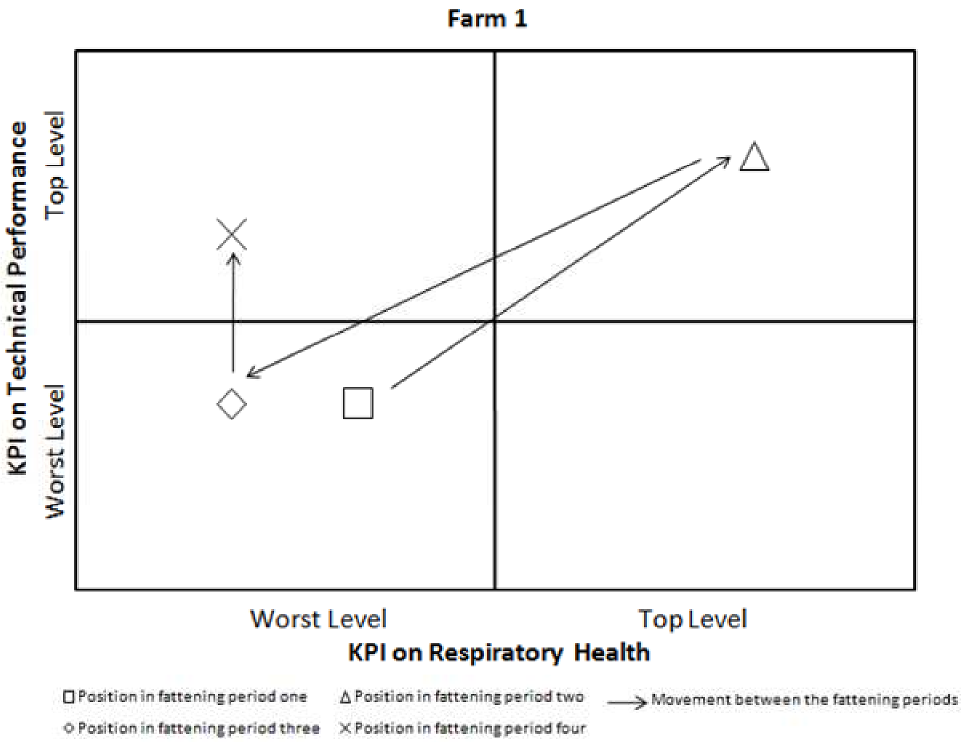

Figure A.28 Highly instable farm 1 on respiratory health and technical herd performance

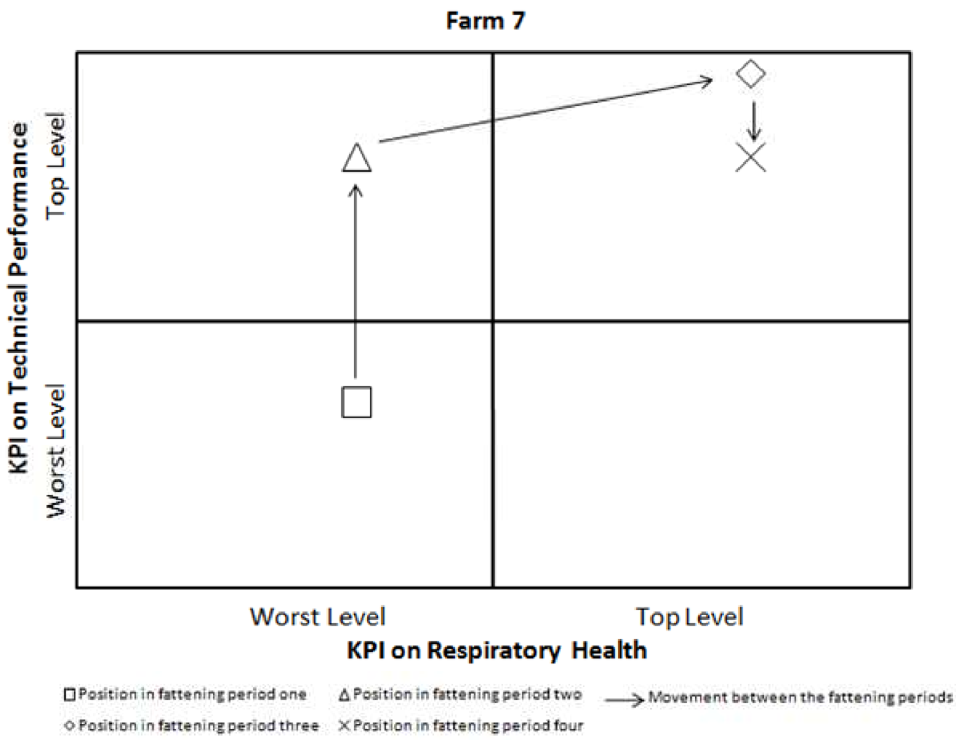

Figure A.29 Highly instable farm 7 on respiratory health and technical herd performance

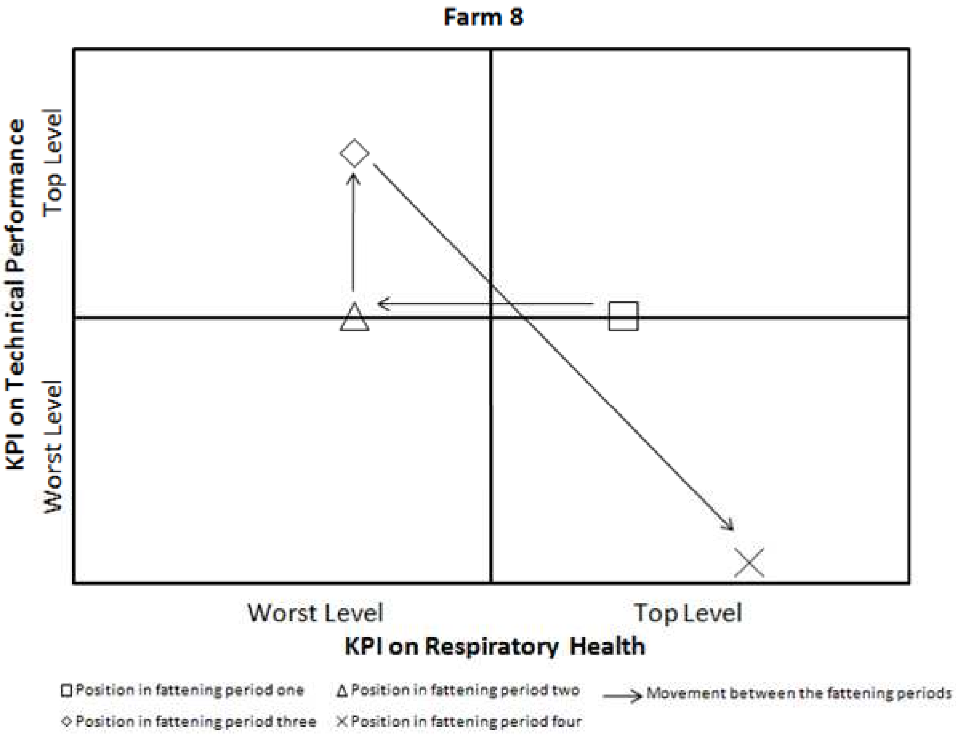

Figure A.30 Highly instable farm 8 on respiratory health and technical herd performance

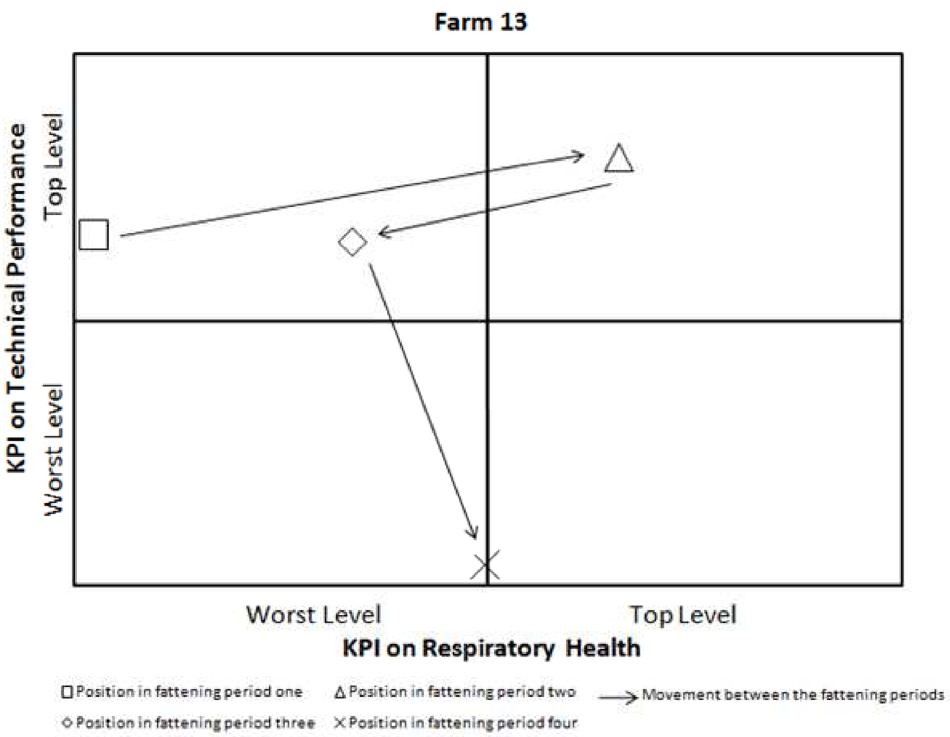

Figure A.31 Highly instable farm 13 on respiratory health and technical herd performance

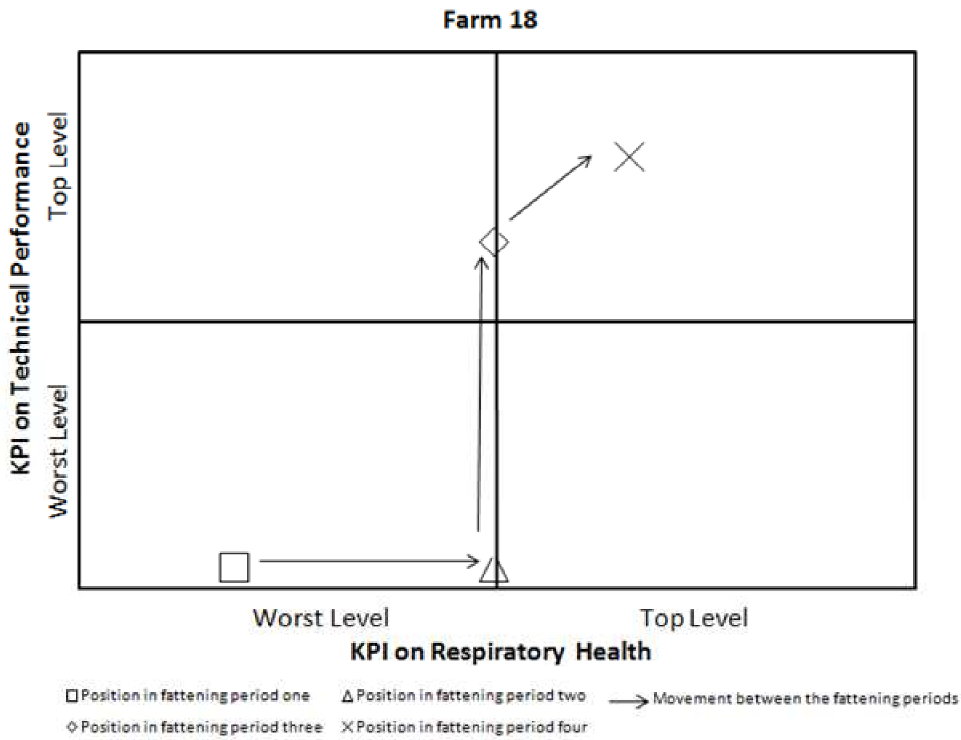

Figure A.32 Highly instable farm 18 on respiratory health and technical herd performance

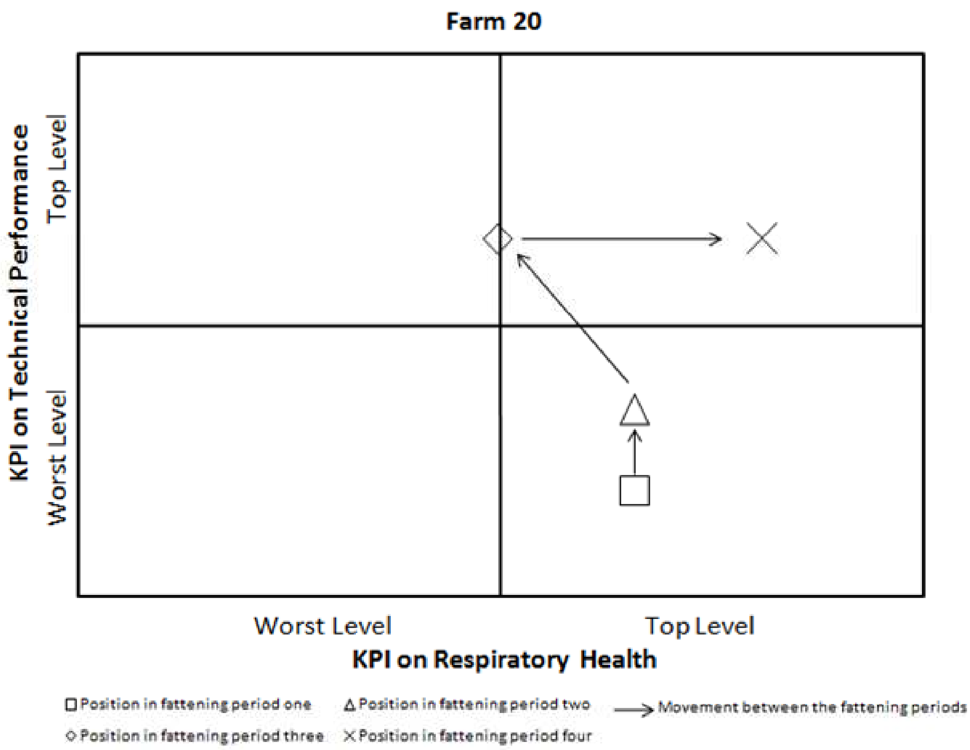

Figure A.33 Highly instable farm 20 on respiratory health and technical herd performance

Table A.2 ELISA positive sample on PRRSV, PCV2, SIV, Mhyo and APP2 per farm and over the four fattening periods

		Fattening period 1					Fattening period 2					Fattening period 3					Fattening period 4				
Farm	Position	PRRSV	PCV2	SIV	Mhyo	APP2	PRRSV	PCV2	SIV	Mhyo	APP2	PRRSV	PCV2	SIV	Mhyo	APP2	PRRSV	PCV2	SIV	Mhyo	APP2
16	ST	0	13	0	0	0	0	0	0	20	0	100	20	0	0	0	100	20	0	0	0
17	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20	0	0
4	SW	60	60	27	100	53	80	80	20	100	100	100	100	60	100	80	100	60	20	100	80
12	SW	100	87	53	87	100	100	80	80	100	80	100	40	40	100	100	100	100	100	100	100
19	SW	100	93	53	93	0	100	40	20	100	0	nn	nn	nn	nn	nn	100	100	20	100	0
2	MI	87	20	87	53	0	100	80	40	80	100	100	100	40	20	100	100	100	40	80	0
3	MI	0	7	0	0	0	0	40	100	80	0	100	40	0	0	0	100	40	0	0	0
5	MI	93	73	20	73	0	100	60	100	80	0	80	60	60	100	0	100	40	0	100	0
6	MI	100	60	0	60	60	100	20	20	100	40	80	20	40	20	40	100	0	80	100	40
9	MI	100	100	0	93	20	100	20	0	100	0	100	60	40	40	0	100	20	0	40	0
10	MI	100	56	56	94	13	100	40	60	0	100	100	60	20	80	0	nn	nn	nn	nn	nn
11	MI	0	47	7	0	0	100	100	60	60	0	0	60	0	0	0	0	40	40	0	0
14	MI	53	13	0	73	0	100	60	0	40	0	100	60	0	20	40	100	60	0	80	0
15	MI	100	21	7	86	0	100	20	20	100	0	100	20	0	100	0	100	0	0	100	20
1	HI	100	100	0	93	0	100	0	100	40	0	100	20	80	60	0	100	60	20	60	100
7	HI	100	53	27	100	0	100	20	40	100	0	60	40	20	0	40	100	0	60	0	0
8	HI	100	63	13	13	0	100	80	40	100	0	100	60	80	100	0	100	60	0	80	0
13	HI	94	100	0	100	100	60	100	20	40	0	100	80	60	100	0	100	40	20	0	0
18	HI	100	73	0	87	93	100	0	40	100	0	100	100	0	100	0	100	40	20	100	0
20	HI	93	27	33	33	33	100	20	0	100	0	100	100	60	80	0	100	0	0	20	0

ST = Stable top level position; SW = Stable worst level position; MI = Moderate instable position; HI = Highly instable position

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During my PhD-project, I had to combine being a PhD-student at University Bonn and with the intention and responsibility to implement an intra-organizational pig herd health management for the Erzeugergemeinschaft Südostbayern eG. I really enjoyed the combination of scientific research on the pulse of time with a practical intention. But after living more than two years out of the suitcases and having more than 150 flights to commute between Eifel and Bavaria it is time to end my PhD-project.

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