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Cost-benefit analysis of an UHF-RFID system for animal identification, simultaneous detection and hotspot monitoring of fattening pigs and dairy cows

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Increasing legal requirements regarding animal welfare on livestock production units that are simultaneously increasing in size require an optimisation of housing conditions with high demands on the management of such farms. Within an innovation project, a UHF-RFID system for simultaneous detection and monitoring of fattening pigs and dairy cows at particular hotspots within the respective housing environments was developed in order to simplify management of farms with larger numbers of livestock. Following many technical advances, there still remains lack of clarity regarding opportunities for UHF systems on the market. To help clarify matters, a cost-benefit analysis was carried out based on four fictive example farms (2 x fattening pigs and 2 x dairy cattle). The results show that the UHF-RFID system applied under the assumptions made offered an economic advantage under the best possible conditions for only one of the dairy farms. Rentability of the system for the other farms could only be achieved if an enormous cost reduction was assumed.

Keywords
Cost-benefit analysis, UHF-RFID, hotspot monitoring, fattening pigs, dairy cows

RFID technology uses different frequency ranges characterised by various attributes. These differ not only in their susceptibility to interference and their data transmission systems, but also in respective transmission distances (Kern 2006).

With the current lower frequency range applied as standard (LF range, ISO 11785 compliant) an error-free simultaneous reading of several transponders by the reader cannot be relied upon. Even when using the so-called anti-collision system, this problem has not so far been solved (Burose et al. 2010). Thus, singling animals is still necessary for reliable identification performance. This means stress for the animals concerned and can mean additional constructional, financial and time investments for farmers (Stekeler et al. 2011).

With systems operating in high frequency (HF) and ultra-high frequency (UHF) ranges, simultaneous reading of transponders is possible (Adrion et al. 2015a, Hammer et al. 2015, Hammer et al. 2016, Maselyne et al. 2014). Additionally, such systems offer advantages of greater transmission distances and higher data transmission rates (Kern 2006). Disadvantageous, especially with UHF, is, however, higher susceptibility to interference factors, such as water and metal, that are unavoidably present through the animals themselves and their housing environment.

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However, there are measures that can be taken, at least in part, against such susceptibilities, through specific further development of transponders (antennae design, support material, etc.) (Adrion et al. 2015b, Catarinucci et al. 2012, Finkenzeller 2012, Hammer et al. 2015). Through the great reading distance capability of passive UHF transponders (> 3 metres) there occurs multiple possibilities for application in livestock production. Not only is simultaneous detection within large groups of animals (e. g. during the loading or transfer into new accommodation of livestock) (Hammer et al. 2016) already possible, but so too is continuous monitoring of certain areas of the housing environment (e. g. troughs, drinking points or environment enrichment devices), at least under trial conditions in test stands and barns (Adrion et al. 2015a).

Cost-benefit analysis (CBA)

Alongside cost-efficiency analysis (CEA) and cost-utility analysis (CUA), cost-benefit analysis (CBA) represents an economic instrument for evaluation of objects, action alternatives and projects (Mühlenkamp 1994). In comparison to CEA and CUA, with CNA the costs, but also the benefits of a project or an action alternative, are evaluated on a monetary basis. In the case of both other systems, monetary evaluation of benefits is not carried out (Musshoff and Hirschauer 2013).

Aim of CBA is monetary evaluation of present and future costs and benefits of a project or an action alternative as well as the discounting and the comparison at a uniform point in time (Müller-Stewens et al. 2015). Hereby, either different action alternatives, or the absolute sustainability of advantage or disadvantage of individual projects, can be assessed (Musshoff and Hirschauer, 2013). The difference between the benefits and the costs given by a CBA result, gives in the first place, information on the action alternative that can be rationally selected as well as information on the meaningfulness of investment in a project.

Especially with information technologies, there often exists lack of clarity over profitability (Verstegen et al. 1995). The once-only costs of such technologies are comparatively simple to calculate based on the market price for purchase and implementation plus operational costs as well as depreciation period, interest charges, applicability of consumption parameters and maintenance aspects. There exist, however, multiple problems in the evaluation of the benefits.

According to Verstegen et al. (1995), the benefit of information technologies is defined as "the difference between the benefits of the best alternative decision under availability of certain information and the benefits of the best alternative without availability of this information (.....)". Pietsch (2003) standardised the benefits of information technologies through two useful effects. To these belong savings when compared with the process applied beforehand for producing the information, and earnings/advantages produced by the application of the information technology. Additionally, the benefits can be subdivided into the descriptive elements quantifiable and non-quantifiable, as well as direct and indirect, benefits.

One reason for the evaluation problems of information technology benefits can lie in the very great range of the information, the multiple performance parameters and decisions, as well as direct and also indirect influences (King et al. 1990, quoted from Verstegen et al. 1995). The person as user has, for example, an important influence on the method of information technology application and, with that, on the resultant benefits (Verstegen et al. 1995). Many authors have, therefore, the point of view that the classic cost-benefit analysis is not sufficient for evaluation of information technology benefits in agriculture (Lincoln and Shorrock 1990, Kleijnen 1980, quoted from Verstegen et al. 1995). These authors propose an addition to the classic cost-benefit analysis with a second step for evaluation of the non-monetary benefit categories.

In the literature, a difference is made between two extended approaches adjusted to suit agricultural requirements. Whereas the benefits of information technology within the framework of the normative approach is theoretically assessed, the positive approach procedure applies empirical studies (field experiments or those in test stations) for assessing the benefits (Verstegen et al. 1995).

Objective

After many technical advances able to be achieved within the framework of the innovation project for development of the electronic UHF ear tag for animal identification (Adrion et al. 2015a, Adrion et al. 2015b, Hammer et al. 2016), there still remained, however, unclarity over market opportunities for the UHF system. For this reason, the costs and the benefits of UHF-RFID system applications are here calculated with the help of application examples (example farms) featuring fattening pig and dairy cattle farms.

Material and methods

Applied UHF-RFID system components

Every UHF-RFID system comprises the fundamental components transponder, reader and computer-supported data processing system. Within this project, function examples for a practically functioning and durable ear tag for cattle and pigs was developed (Figure 1) and used in the case studies.

Figure 1: Ultra-high frequency pig and cattle transponder ear tags (© N. Hammer)

Along with the UHF transponder ear tags, two different UHF readers from deister electronic, Barsinghausen were used in the fictively installed system. With the first reader (TSU 200, deister electronic 2012) all the electronics including antennas are part of the housing with no possibility of attaching additional external antennas. Two of these readers were used for recording animals in groups moving within passages whilst changing housing area or loading for transport (gate usage). The second reader (TSU 200 Mux) permitted attachment of up to four external antennas. The advantage of these four external antennas lies in the possibility of applying them flexibly within the animal management system with the ability of scanning a number of places within the building. This reader was used for hotspot monitoring of animals in the example cases. The TSU 200 Mux is built by Agrident GmbH with casing suitable for the demands of livestock production (temperature fluctuations, dust, dirt, water splashing). Both readers have a maximum output performance of 1 W.

Different external antennas could be attached to the TSU 200 Mux. Within the example farms presented here, an antenna from the company Kathrein RFID, Stephanskirchen, Mira 52010082‘ and an external antenna from MTI Wireless Edge Ltd., Rosh-Ha’Ayin, Israel, Antu Patch 63‘ were used. The antennas differed mainly in their respective reception opening angles. Depending on the application location, a larger or a smaller opening angle can be practical. Figure 2 shows both readers used, as well as comparing both antenna types.

Figure 2: Reader TSU 200 with integrated antenna, TSU 200 Mux with four external antennae connections, external antenna from Kathrein-RFID, “Mira 52010082” and external antenna from MTI, “Antu-Patch 63” (l to r) (© F. Adrion)

Also required for application of the UHF system were a few cables and other electrical components. Within the system described here, coaxial cables provided connections between readers and antennas. The coaxial cables were attached to the antennas via type N coaxial connections. The reader and the computer-supported data processing system were connected by 4-pole control cable with RS-485 BUS system and 24 V power supply. This cable led to a control cabinet within which the control cabling of all readers mounted in the respective barns ran together. The cabinet also included the central power supply for the readers. The data from the readers were collected from the serial interfaces onto an ethernet interface with help of “serial device servers”. The computer features an ethernet switch upstream in order to provide sufficient ethernet cable connections. Figure 3 shows a diagram of the applied UHF-RFID system hardware components within a barn.

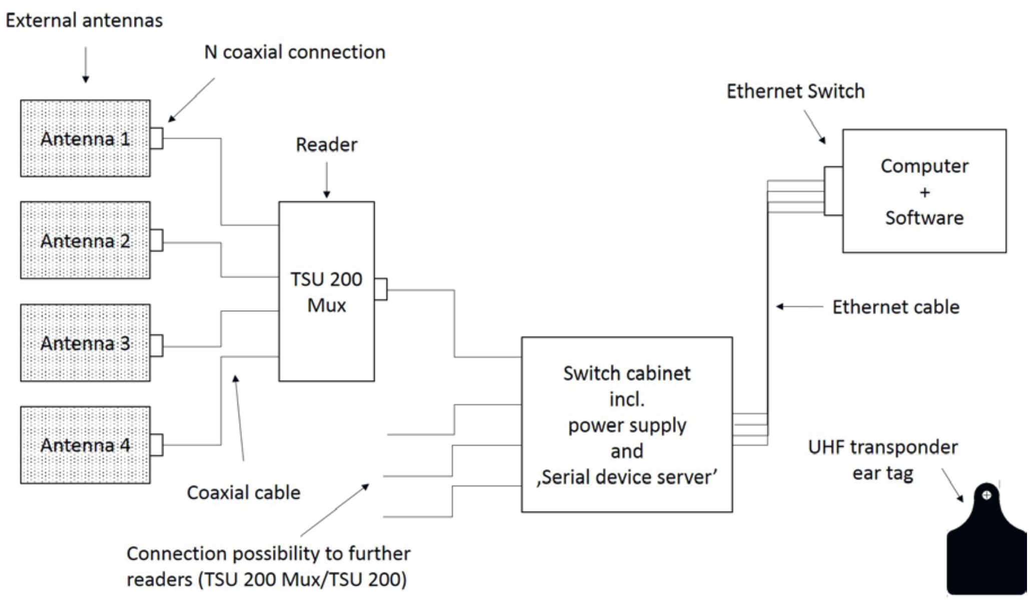

Figure 3: Diagram depicting layout of the applied UHF-RFID system

Within the computer, the recorded data of the UHF-RFID system is further processed by software from Phenobyte GmbH and Co. KG, Ludwigsburg which was specially developed for this purpose. This software accomplished various different tasks according to the situation and respective application field. Involved was the processing of data from simultaneous reading of animal groups, or reading of animals in different hotspots within their housing environment. Also undertaken by the software was depiction of visit incidents, or length of time of visits, at the previously determined hotspots, and the production of 'alarm lists'.

Case studies

The calculations of costs and benefits of the described UHF-RFID system for electronic animal identification were carried out for example farms. For this, were selected two differently sized fattening pig barns (an alternative management form with Pig Port 3 vs. conventionally managed farm) and two dairy cow barns (typical family farm vs. larger farm with hired labour).

Barn A – natural ventilation barn for fattening pigs (Pig Port 3) (400 fattening pigs):

Natural ventilation barns for fattening pig production according to Fritzsche und Van den Weghe (2009) provide an alternative to fully-enclosed insulated and forced ventilation housing and are mainly used in ecological/organic livestock management systems and in production systems serving welfare-based labels.

The Pig Port 3 system (Figure 4) selected for the cost benefit analysis had 400 fattening pig places. The barn featured a partly roofed outrun available to the pigs as activity space (Zimmer and Brede 2014). Each of the planned 20 pens could hold 20 animals.

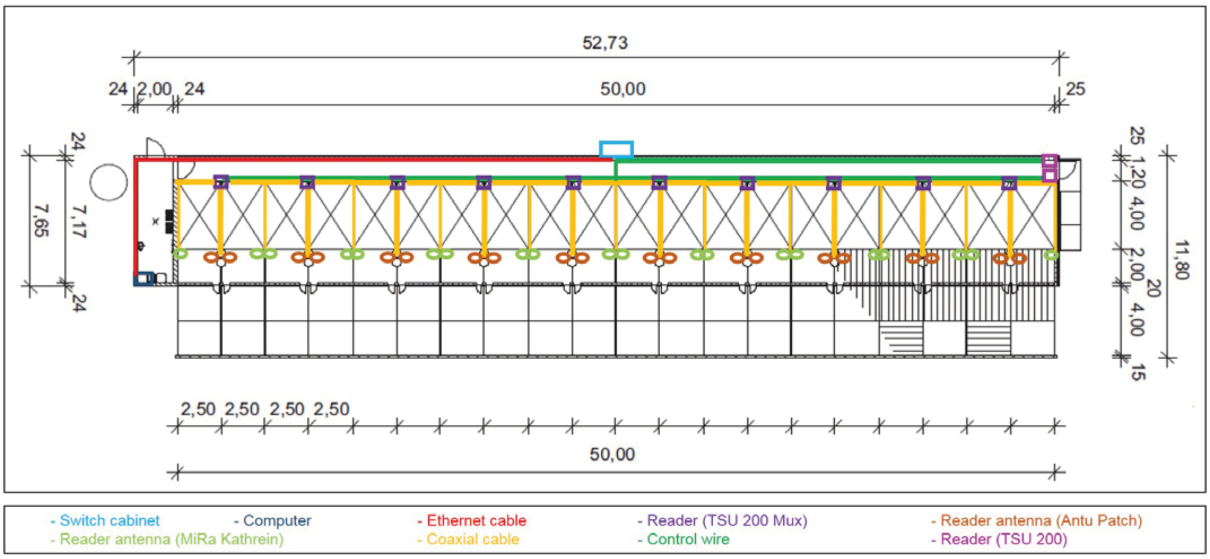

Figure 4: Plan elevation of example barn A for 400 fattening pigs with schematic illustration of the inbuilt RFID system hardware components (© KTBL 2015a, adjusted)

As shown in Figure 4, the naturally ventilated barn was equipped fictively with a UHT-RFID system. Used in total were ten TSU 200 Mux readers, each connected to four antennas. One reader antenna (Kathrein MiRa) was inserted per pen, in each case attached to nipple drinkers on the pen walls and above each mash tube feeder was an MTI Antu Patch antenna. At the end of the feeding passage at the loading ramp, two TSU 200 were installed as readers. The switch cabinet was planned in the middle of the feeding passage. The computer was situated in the barn office. In total, 266 m of antennas cable, 187 m of control wiring and 38 m of ethernet cable were laid.

Barn B – enclosed, force ventilated fattening pig barn with large groups (1600 fattening pigs): "The closed and force ventilated barn without litter and with insulated lining and heating is standard in fattening pig production" (Fritzsche and Van den Weghe 2007) and because of this was selected as one of the examples for the following cost benefit analysis. Shown here in detail is example barn B (Figure 5) with a total 1600 fattening pig places. Incorporated are 40 pens, each holding 40 animals.

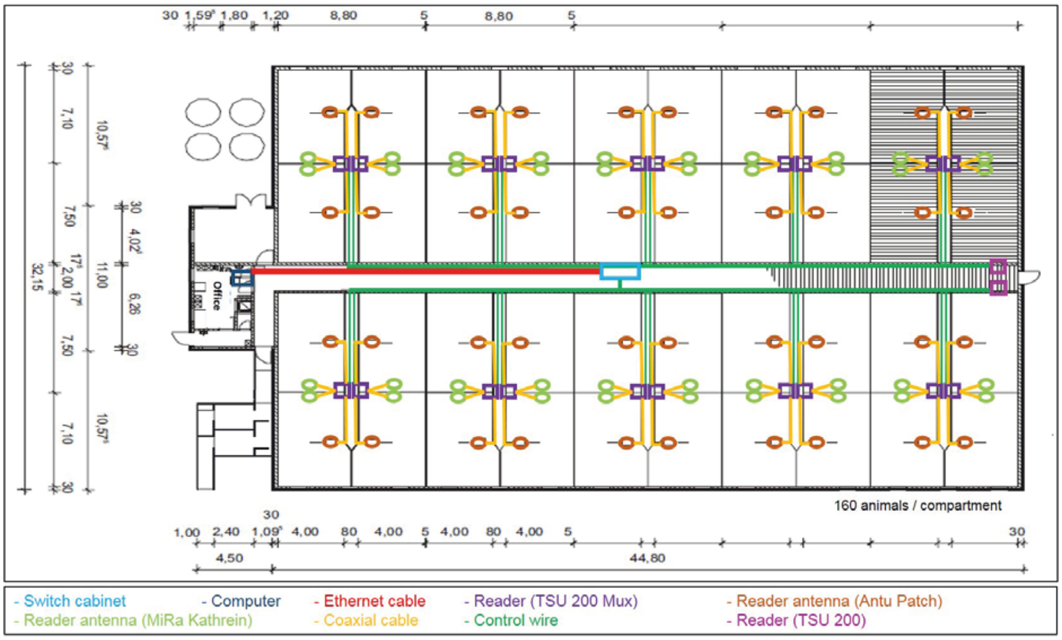

Figure 5: Plan elevation of example barn B for 1600 fattening pigs with illustration of fitted RIFD system hardware components (© KTBL 2015b, altered)

Also in the plan of the example barn B, all drinkers are fitted with a reader antenna Kathrein MiRa and all tube mash feeders with the antenna MIT Antu Patch. In total, 20 TSU 200 Mux, 40 Kathrein MiRa and 40 MIT Antu Patch antennas were fitted. Once again, a reader was planned at the end of the feeding passage by the loading ramp with the help of two TSU 200 antennas. In total, 450 m antennas cable, 417 m control wiring and 26 m ethernet cable were calculated.

Barn C – cubicle barn with outdoor run for 71 dairy cows (71 cows):

As example C (Figure 6), a double-row cubicle barn with 71 cow places was selected as representative of a family-run dairy farm in Germany. A special aspect of the example barn C was the solid-floored outdoor run. Barn C featured a 2 x 8 herringbone parlour preceded by a waiting area.

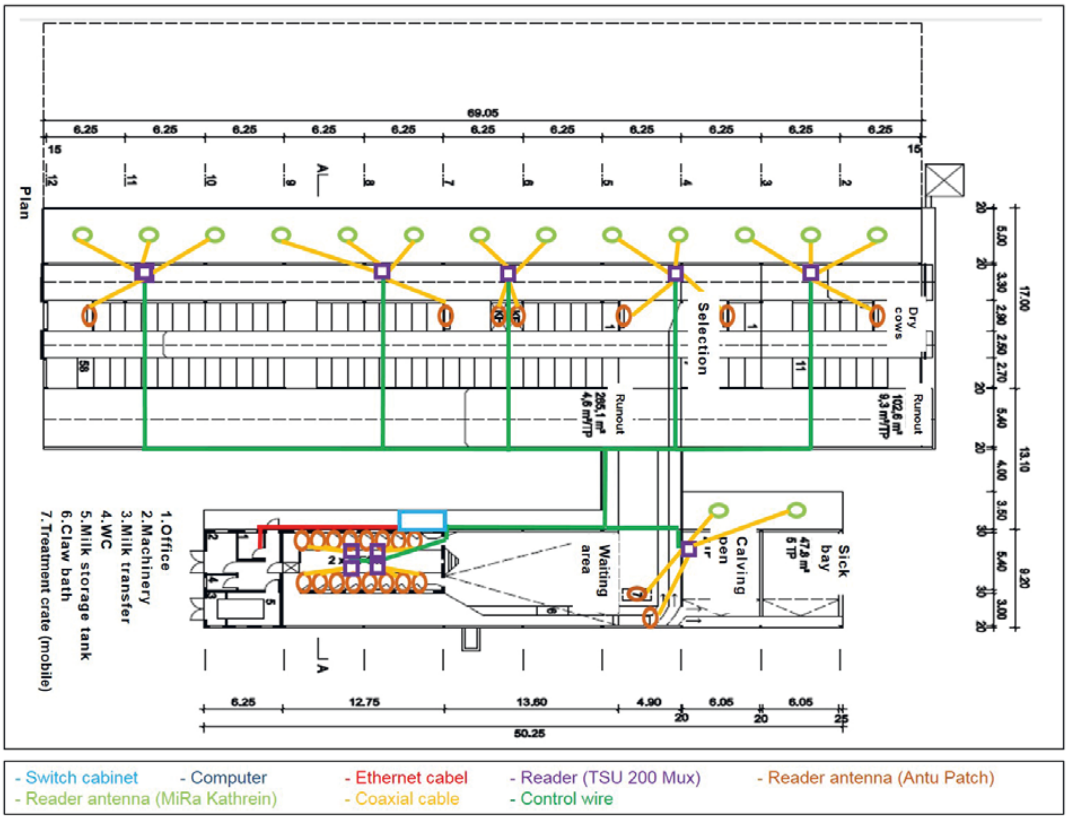

Figure 6: Plan elevation of example barn C with diagram of fitted RFID system hardware components (© KTBL 2015c, adjusted)

In the example barn C plan, the feeding table is in each case fitted with the Kathrein MiRa reader antennas, because these have a larger opening reception angle than that demonstrated by the MIT Antu Patch antennas. The number of antennas was calculated in such a way that the reader cones just overlapped on the feeding table surface and so the entire feeding table was effectively radiated. The cow positions in the parlour and each drinking point and two concentrate dispensers were each fitted with an MIT Antu Patch antenna. In total, the barn was planned to be fitted with ten TSU 200 Mux, 25 Antu Patch and 15 MiRa Kathrein antennas with 215 m antennas cable, 332 m control wiring and 16 m ethernet cable.

Barn D – cubicle barn for 624 dairy cows (624 cows):

Example barn D (Figure 7) is laid out as a as a double three-row cubicle barn with solid floored passages and scraper mucking for 624 dairy cows to represent larger dairy farms with hired labour.

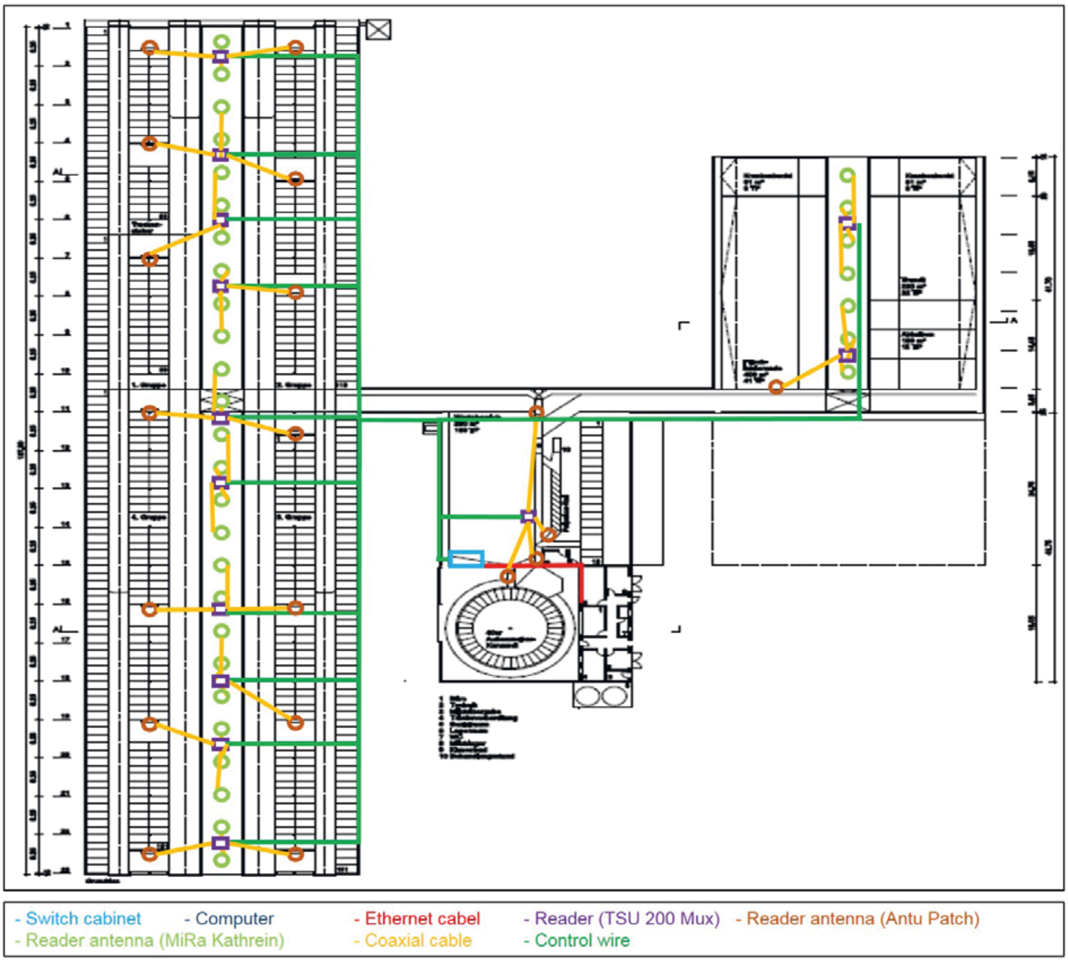

Figure 7: Plan elevation of example barn D for with diagram of fitted RFID system hardware components (© KTBL 2015d, adjusted)

The cows in example barn D were milked in an outer milking system, a 40-point carousel parlour with waiting area for around 160 cows. Planned for the barn were once again MiRa Kathrein antennas for the feeding table and Antu Patch antennas for drinking troughs as well as for carousel parlour entrance. This plan did not include concentrate feeders. Planned were in total 13 TSU 200 Mux, 19 Antu Patch and 33 MiRa Kathrein antennas with 382 m antennas cable, 1131 m control wiring and 24 m ethernet cable.

Calculating the costs

The costs of the described UHF-RFID system were calculated under the following assumptions:

- All farms selected the complete equipping of barns with the UHF-RFID system (fattening pigs: fitting of all troughs and drinking points (hotspot application) as well as loading ramp (gate application); dairy cows: fitting of feeding table, all watering points and concentrate feeders (hotspot application), as well as parlours (individual animal identification). In the dairy farms, the examples here had no readers at loading ramps. For more detailed information, see Figures 4 to 7.

- All the farms already use a farm computer which can also be available for processing the data from the systems described here.

Total costs of the system comprise material costs (hard and software as well as initial fitting with UHF ear tags for dairy cows), fitting and installation costs, costs occurring on an annual basis for new UHF transponder ear tags, energy costs and costs for depreciation and interest (according to information from Potthof 1998, Pietsch 2003) (Table 1). On the basis of the barn layout were calculated the required number of components and the necessary lengths of cable for the UHF-RFID system. Any costs for infrastructure alterations in form of new constructions or rebuilding measures were, however, not considered.

Under these preconditions the costs of the UHF-RFID systems were additionally worked out for two different situations:

1. Maximum costs of the UHF-RFID system (current costs, cost situation CS 1).
2. Reduced costs of the UHF-RFID system (costs assessed by the manufacturer after market establishment, cost situation CS 2).

Table 1: Cost blocks and appropriate procedure in cost calculations and also basic assumptions for calculations

Cost item	Appropriate procedure for calculation	Basis of calculations/assumptions
Fixed costs		
Material costs	Requested information from manufacturer or project partner/ online research	Hardware costs differ, depending on product, software costs: 50,000 €; CS 1: 50 licences; CS 2: 100 licences; Incl. 8.0 % of total software costs for annual updates as from second year. Costs for original UHF ear tags (dairy cattle only)
Fitting and installation costs	Calculation	Installation time: 0.5 labour hours per antenna plus 8.0 labour hours additional work; hourly rate: 40 € (own experience)
Variable costs		
Costs of UHF transponder ear tags	Requested information from manufacturer or project partner/ calculations	Number of required transponder ear tags based on average values from KTBL. Pigs: 2.85 production cycles/year multiplied with assessed ear tag price (CS1 1.5 €; CS2 1.05 €); Dairy cows: replacement rate 37 % (Frisch et al. 2014) multiplied by supplied ear tag price (dairy cows: CS1 2.50 €; CS2 2.10 €)
Energy costs	Calculation	Considers only energy consumption of readers 24 h/365 d per year. Additional calculation for 70 % and 50 % working time. Assumption: power requirement per reader = 0.024 kW (deister elecetronic 2012); Electricity price 27 ct/kWh (RWE 2015)
Calculation		
Purchase costs	Literature/calculations	Sum of material costs, fitting and installation costs
Depreciation	Literature/calculations	Assumption: Five year working lifetime (Verstegen et al. 1995). Depreciation: purchase cost per 5 years
Interest costs	Literature/calculations	Interest at 4.0 % applied as compound interest rate for own and foreign capital (Omelko and Schneeberger, 2005). Interest costs: purchase costs/2 · 0.04 (KTBL 2012)
Total annual costs	Literature/calculations	Sum of fixed (depreciation + interest) and variable (energy + ear tag) costs per year

Cost item	Appropriate procedure for calculation	Basis of calculations/assumptions
Cost per animal place	Literature/calculations	Annual total costs/number of animal places per management system (Pigs: 400 and 1,600; dairy cows: 71 and 624) (KTBL 2015e-h)
Costs per product unit	Literature/calculations	Annual total costs/kg of product (pigs: barn A = 94,548 kg meat; barn B: 420,336 kg meat (KTBL 2015e, f); dairy cows: barn C: 514,750 kg milk; barn D: 5,304,000 kg milk) (KTBL 2015g, h)

CS = Cost situation

Determining the benefits

The determination of the benefits is limited to benefit categories from the farmer's point of view, all further possible perspectives (law maker, authorities, livestock, etc.) being ignored. Otherwise, determination of benefits followed recommendations from Verstegen et al. (1995), so that monetarily assessable values as well as non-monetary assessable benefit categories are taken account of (Table 2). The quantification of the monetarily assessable benefit categories was undertaken through application of differing scenarios. Based on the scenarios (potential savings from 2, 5 or 10 % of production costs in various benefit categories) the benefits, representing the sum of the gross benefits of the UHF-RFID system, are monetarily evaluated. The system net benefits are calculated by subtraction of the costs from the gross benefits. Applied for all benefit categories are KTBL cost efficiency calculations for the appropriate management procedure, production system and housing size (www.ktbl.de/online-anwendungen). Hereby in each case an average production level is accepted.

Table 2: Observed benefit categories, the assumptions and scenarios (reduction of production costs by 2, 5 and 10 %) as well as evaluation possibility.

Benefit category	Assumptions applied for starting situation and non-monetary effects	Evaluation
Early identification of disease (Veterinary treatment and medicine cost savings)	Costs for vets and medicine: • Pigs: ø 2.60 € per animal place and year under tendential organic management (barn A) and 4.30 € for conventional management (barn B) (KTBL 2015e, KTBL 2015f). • Dairy cattle: 50 € per cow and year (KTBL 2015g, KTBL 2015h)	monetary
Efficient livestock controls (Cost savings on ø labour time for livestock control)	Labour time: • Tendentially organic pig production (barn A): 0.5 work hours per animal place and year (KTBL 2016) Large-scale conventional fattening pig unit (barn B): approx. 0.3 work hours per year and animal place (KTBL 2016) • Smaller and larger-scale dairy units with herringbone parlour (barn C) and carousel parlour (barn D) approx. 3 work hours per animal place and year (KTBL 2016); assumed hourly pay rate: 17.50 € (KTBL 2015e)	monetary
Combination of interfarm and individual farm livestock ID (Only for dairy cows. Cost savings through discontinuation of current ID, e. g. collar).	Annual animal ID costs 5 € per animal place (KTBL 2015e, KTBL 2015f, KTBL 2015g, KTBL 2015h).	monetary
Fertility management (For dairy cows only: reduced inseminations, semen)	Insemination, semen and service fees 25 € per animal place and year (KTBL 2015g, KTBL 2015h).	monetary
Simultaneous detection of animal groups	Improvement of animal welfare, increased work safety (greater scanning distance, no singling out).	non-monetary
Data and information pertaining to individual animals	Strategic (selection according to genetics, disease susceptibility, performance data, i. e. control instrument as basis for single animal based management)	non-monetary

Within the following survey, the costs and benefits of the information system are theoretically assessed, in other words, the normative approach is applied. But because the information system to be used had already been tested on experimental farms, some results from field experiments could be brought into the calculations.

Results and discussion

Costs

The resultant costs of the UHF-RFID system as described in Table 1 were calculated for the fattening pig barns as well as the dairy barns, under both cost situations. The determined annual total costs, costs per animal place and per production unit of the example farms are presented for both cost situations in Tables 3 and 4. Additionally, the saving potentials of CS 1 to CS 2 are given as percentages. In the case of fitting and installation costs, as well as annual running costs, the costs of CS 1 and CS 2 were not altered for the fattening pig or dairy farms.

Table 3: Details of all costs (in €) of the UHF-RFID systems for fattening pig barn A (stocking: 400) and B (stocking: 1600) in cost situations 1 and 2, as well as percentage cost reduction (rounded up)

Pigs	**Cost situation 1 in €**		**Cost situation 2 in €**		**Cost reduction in %**	
Cost block	**Barn A**	**Barn B**	**Barn A**	**Barn B**	**Barn A**	**Barn B**
Material costs in total	27,764	46,413	16,264	26,033	41	44
of which hardware costs	26,444	45,093	15,604	25,373	41	44
of which software costs	1,320	1,320	660	660	50	50
Fitting and installation costs	1,120	1,920	1,120	1,920	0	0
Annual running costs	681	1,249	681	1,249	0	0
Annual ear tag costs	1,710	6,840	1,197	4,788	30	30
Purchase costs in total	**28,884**	**48,333**	**17,384**	**27,953**	**40**	**42**
Interest costs	**578**	**967**	**348**	**559**	**40**	**42**
Depreciation 5 years	**5,777**	**9,667**	**3,477**	**5,591**	**40**	**42**
Annual total costs	**8,746**	**18,722**	**5,703**	**12,187**	**35**	**35**
Costs per animal place	**21.90**	**11.70**	**14.30**	**7.60**	**35**	**35**
Costs per kg meat	**0.092**	**0.045**	**0.060**	**0.029**	**35**	**35**

Table 4: Detailing of all costs (€) of the UHF-RFID system for dairy farm C (71 cows) and dairy farm D (624 cows) in cost situations 1 and 2, as well as percentage cost reduction (rounded up).

Dairy cows	**Cost situation 1 in €**		**Cost situation 2 in €**		**Cost reduction in %**	
Cost block	**Barn C**	**Barn D**	**Barn C**	**Barn D**	**Barn C**	**Barn D**
Material costs in total	26,803	33,693	15,894	20,370	41	40
of which hardware costs	25,305	30,813	15,085	18,400	40	40
of which software costs	1,320	1,320	660	660	50	50
of which initial equipment Ear tags	178	1,560	149	1,310	16	16
Fitting and installation costs	1,120	1,360	1,120	1,360	0	0
Annual operating costs	568	738	568	738	0	0
Annual ear tag costs	66	577	55	485	16	16
Purchase costs in total	**27,923**	**35,053**	**17,014**	**21,730**	**39**	**38**
Interest costs	**558**	**701**	**340**	**435**	**39**	**38**
Depreciation 5 years	**5,585**	**7,011**	**3,403**	**4,346**	**39**	**38**
Annual total costs	**6,776**	**9,027**	**4,366**	**6,003**	**36**	**33**
Costs per animal place	**95.40**	**14.50**	**61.50**	**9.60**	**36**	**33**
Costs per kg milk	**0.013**	**0.002**	**0.008**	**0.001**	**36**	**33**

As can be seen from Table 3, material costs (≈ 96 %) and particularly hardware costs (> 88 %) make up the largest part of purchase costs in all four example farms. Also in CS 2 (Table 4) where the assumed material costs are reduced by approx. 40 %, these still represent the largest proportion. However, the hardware costs represent not only the largest proportion of material costs but also the largest proportion of annual total costs. The high percentage proportion of material costs when all costs are considered for all the farms observed here tends to be unusual for an information system. For instance, with Andres (2009) only 20 % of total hardware costs were caused by hardware. There, with a total of approx. 75 %, wage and licence costs represented by far the highest proportion of total costs (Andres 2009). This UHF-RFID system is not yet established in practice. For this reason, the costs of system components not greatly in demand so far are substantial. This especially applies to the reader costs. UHF readers and the required connections and cables for use in the challenging open farm environment have to be especially protected (splash proof, dust and ammonia proof, where required protected against biting), all of which increases manufacturing costs.

Perspectives for cost reduction:

Hardware

The reader devices featured here are still in the development stage. An estimated reduction of up to 50 % in reader costs through these systems coming onto the market (CS 2) can be assumed (own assumptions, reached through discussions with experts). Additionally, there is offered through the application examples presented here (hotspot monitoring) UHF readers that enable the attachment of a number of (>4) external antennas. An example is the Impinj Speedway (Impinj Inc., Seattle, WA, USA), which, via an antenna hub, enables the connection of 32 external antennas (Impinj Inc. 2015). With this, the number of readers in the featured example barns would be reduced by a large factor and the costs thus substantially lowered (barn A: − 8 readers; barn B: − 17 readers; barns C: − 8 readers; barn D: − 11 readers). This would correspond in the case of barn B and CS 1 to a saving for the entire system of up to 17,000 €, in other words − 30 % of hardware costs. However it can be seen that this optimistic assessment does not take into account additional costs for probably more expensive coaxial cables and for the required antenna hub. Also, the price of the Impinj Speedway 32 port as possible reader could not be exactly established. Its suitability for application in a barn environment is questionable and a modification of the reader for usage in a barn environment would probably be associated with further costs.

Costs for external antennas in the example application used here are calculated as fairly high. The high starting performance of the antennas selected and used in this case would probably be only necessary on the feed tables of a dairy unit. For calculation of the UHF-RFID system as presented here, only antennas which could be tested beforehand in self-conducted trials for their basic suitability were applied. On the drinking points and feed troughs of the fattening pig barns, as well as in the milking parlour of barn C, smaller- dimensioned antennas with reduced performance would very probably be suitable. These antennas would be somewhat cheaper and also already established on the market (see metraTec® Echo-N UHF-Antenne, metraTec GmbH, Magdeburg). However, such antennas, also have the problem of limited suitability for in-barn use at this stage.

The number of antennas can also be optimised. In barn C (71 cows, 2 x 8 milking parlour) attachment of an antenna for every milking point could be done without, for example. With software to sequence the order of animals entering the parlour, only two antennas are required: one on each side of the parlour. A reduction of 14 external antennas (- 8.5 % of hardware costs) is thus possible in CS 1. In any case, such an application would be practical with larger dairy units, e. g. those using a milking carousel and was planned as example in barn D (624 cows).

Software

The software costs lie substantially under those of hardware in all units under both cost situations and thus represent a markedly lesser proportion of purchase costs (between 2 and 5 %, depending on type of livestock, housing system and CS) and therefore of annual total costs. For CS 1 and 2, software costs were reduced by around 50 % through allocation of an increased number of licences (from 50 to 100 licences). Through allocation of further licences on more than 100 farms, the costs for software could once again be reduced.

The software costs as reported by Verstegen et al. (1995) showed a different reaction. When only a computer, printer and software were required, the cost of software (incl. annual updates) exceeded markedly those for hardware (software costs = 68 %), although, here too, software update costs of approx. 8 % were calculated-in.

Fitting and installation costs

Fitting and installation costs also proved to represent a very small proportion of purchase costs compared with hardware costs in both farms, representing between 4 and 7 %, depending on livestock type, housing system and CS. Thus, their share and that for the software costs, represent a limited proportion of annual total costs. However, these costs are also difficult to estimate. Here exists, alongside regional differences, also uncertainties over practicability and flexibility of the final developed systems. “Plug and play” solutions were aimed for. However, because of the many different livestock housing forms, these are difficult to realise.

Energy costs

Not to be neglected are also reader variable energy costs. In CS 1, these have a share of between ≈ 7 and 8 % and, in CS 2, a share of between ≈ 10 and 13 % of annual total costs, depending on livestock type and management system.

As with the hardware costs, there exists with the example farms and their respective energy costs optimisation requirement. For the above presented example farms, reader running times of 24 hours and 365 days in year were assumed in order to simplify calculation of total costs. These have to be readjusted. For instance, correctly adjusted readers could switch-on only when a transponder comes into range (Hammer et al. 2015) thus offering a substantial reduction in energy costs in practical application. This approach also applies in barn B. With an assumed running time of 70 % of total time, energy costs in CS1 could be reduced by an annual ≈ 874 € (30 %). The total costs from CS 1 would be reduced through this alone by an approx. further 2 %. With a reduction of 50 %, a further reduction in annual total costs of > 3 % could be achieved. In barn D, and a reduction of 50 % in energy costs, the annual total costs in CS 1 could be reduced by as much as >4 %.

Ear tags

The costs for ear tags have, especially in the fattening pig barns (A and B) a not insignificant proportion (between≈ 20 and 40 %, according to housing system and CS) of the annual total costs. In barn C the proportion of costs for ear tags compared to total annual costs was only approx. 1 % and in barn D between ≈ 6 and 8 %.

The proportionally high costs for the pig transponder ear tags is through the large number of ear tags required. With 1,600 pig places (barn B) and an assumed 2.85 batches per year (KTBL 2015f), this already means a requirement of 4,560 ear tags, in that all tags leave the farm with the pigs when they go to slaughter. Through hygienic and labour cost grounds, re-using the ear tags is not practical. Additionally, the aim is to achieve a combination of transponder ear tag and farm ear tag for identifying each animal so that, on leaving the unit, the ear tag must remain with the animal.

With dairy cattle, a milking herd animal replacement rate of 37 % was assumed (Frisch et al. 2014). In that a good durability of the transponder ear tags is assumed, and the cows remain longer than one year in the unit, every cow does not require one or more ear tags each year (UHF ear tag requirements per year being therefore only 37 % of the herd). The first equipping of dairy cows with UHF ear tags was integrated into the material costs in order to separate these better from the annual costs. Through this, the proportion of ear tag costs within the annual total costs of dairy production was substantially smaller.

Costs per animal place and product unit

Furthermore, large differences can be identified between the individual costs per animal place depending on type of animal or management system and production unit. Behind this situation is the markedly different livestock stocking per farm unit and, with that, the different levels of production. The UHF-RFID system on farm C is not especially lower cost than that of farm D although fewer animal places mean total costs are divided between fewer production units. Additionally, it can be said that a central feeding table as in barn D, where the animals can feed from both sides, represents a good suitability for the UHF-RFID system. Through the central positioning of the antennas, two feeding gates can be radiated and thus antennas saved.

Benefits that can be evaluated monetarily

Listed in Tables 5 and 6 are benefit categories that can be evaluated monetarily. Because the benefits that occur in a barn are unable to be precisely forecasted because of the many-layered differences in farm businesses, calculations are made here based on scenarios of a 2, 5 and 10 % reduction in applied costs for the benefit categories “Early identification of disease” “Efficient livestock control”, “Combination of inter and individual farm animal ID” (only dairy cattle) as well as “Fertility management” (only dairy cattle).

Table 5: Gross benefits and saving potentials of the UHF-RFID system in fattening pig management under different scenarios (rounded up)

	Barn A (400 fattening pigs)			Barn B (1600 fattening pigs)		
Benefit category in € per barn and year	**Scenario 1 −2 %**	**Scenario 2 −5 %**	**Scenario 3 −10 %**	**Scenario 1 −2 %**	**Scenario 2 −5 %**	**Scenario 3 −10 %**
Early disease identification[1)]	21	51	103	137	342	685
Efficient animal control[2)]	70	175	350	168	420	840
Annual savings potential in €	**91**	**226**	**453**	**305**	**420**	**1,525**
Annual saving potential in € per animal place	**0.20**	**0.60**	**1.10**	**0.20**	**0.50**	**1.00**
Annual saving potential in € per kg	**0.001**	**0.002**	**0.005**	**0.001**	**0.002**	**0.004**

Assumptions:
1) Vet and medicine (€ per animal place and year) barn A = 4.30 €, barn B = 2.60 €.
2) Labour time requirement for animal control (hourly labour input per animal place and year) barn A = 0.3 h, barn B = 0.5 h; 2.85 batches per year.

Table 6: Gross benefits and saving potentials of the UHF-RFID system in dairy cattle management under different scenarios (rounded up)

	Barn C (71 dairy cows)			Barn D (624 dairy cows)		
Benefit category in € per barn and year	**Scenario 1 −2 %**	**Scenario 2 −5 %**	**Scenario 3 −10 %**	**Scenario 1 −2 %**	**Scenario 2 −5 %**	**Scenario 3 −10 %**
Early disease identification[1)]	71	178	355	624	1,560	3,120
Efficient animal control[2)]	75	186	373	655	1,638	3,276
Combination of inter and individual farm animal control[3)]	7	18	36	63	157	315
Fertility management[4)]	36	89	178	312	780	1,560
Annual saving potential in €	**188**	**471**	**941**	**1,654**	**4,135**	**8,271**
Annual saving potential in € per animal place	**2.70**	**6.60**	**13.30**	**2.70**	**6.60**	**13.30**
Annual saving potential in € per kg	**0.000**	**0.001**	**0.002**	**0.000**	**0.001**	**0.002**

Assumptions:
1) Vet and medicines (€ per animal place and year) barn B + C = 50 €.
2) Hourly labour input for animal control (hourly labour input per animal place and year) barn C = 3 h, barn D = 3 h.
3) Animal identification (€ per animal place and year) barn C + D = 5 €.
4) Insemination, semen, service fees (€ per animal place and year) barns C + D = 25 €; replacement rate 37 %.

It can be seen that, even with a 2 % reduction in costs in every benefit category, an annual saving potential in fattening pig management of ≈ 91 € in barn A and 305 € in barn B is possible, which must then be calculated against the existing costs of the system (Table 5). With a very optimistic reduction of costs of 10 % for all benefit categories, there could be saved through the system up to ≈ 453 € in barn A and 1,525 € in barn B.

With the dairy cow barns, the saving potential is respectively higher (Table 6). If only 2 % of the costs of all benefit categories in barn C is saved, in this way a total ≈ 188 € of the total costs could be saved. With an optimistic saving of 10 %, ≈ 941 € could be saved. In barn D a saving potential of ≈ 8,271 € could be calculated for the 10 % scenario.

Annual savings potential

As with the cost calculations, the yearly savings potential per unit is greatly dependent on type and size of farm unit. Thus, the larger units have a substantially greater annual saving potential compared with smaller ones. With regard to savings potential per animal place and product unit, the situation is, however, completely the other way around because the saving potentials with the smaller farms are distributed over less animal places and product units, and are therefore larger.

Early identification of disease

Especially with fattening pigs managed in larger groups, the timely recognition of diseased individual animals is important. Under the assumptions in table 2 there is in barn A (400 feeding places), according to KTBL (2015e), an assumed better animal health than in barn B (KTBL 2015f). In the former, there are costs of approx. 1,028 € for vet and medicines. In barn B (1,600 feeding places) yearly costs are 6,848 € in this respect. Also with dairy animals, farm C with 71 cows requires 3,550 € for annual total vet and medicine costs and for barn D with 624 cows 31,200 € (KTBL 2015g, KTBL 2015h).

Through the application of the system and software presented here, disease could be identified on an animal individual basis through drinking, feeding and movement behaviour and thus treated early. According to many authors, especially with fattening pigs attention to drinking behaviour can support decisions regarding individual intestinal diseases (Kashiha et al. 2013, Madsen et al. 2005, Madsen and Kristensen 2005). Cornou et al. (2008) already use the feeding behaviour for recognition of lameness and health problems with sows managed in groups. Feeding behaviour of fattening pigs can also be used to determine optimum feed rations (Nielsen et al. 1996). In this way, additional savings may be realised in the area of feed costs. Optimum feeding of fattening pigs can, according to Niemi et al. (2010), bring an annual saving of 1.35 € to 1.88 € per animal place. Jensen et al. (2012) investigated the economic effects from lame fattening pigs based on nine different cases. Here, a reduction in the profit range from on average 0.80 € for hoof problems up to 55 € with fractures could be determined (Jensen et al. 2012).

With calves, too, animal individual and precise feeding techniques can lead to the amount of liquid consumed being managed through attention to individual concentrate rations intake. In that the concentrate consumption of calves represents a more sensitive parameter than the amount of liquid consumed, there results not only savings in expensive milk replacement but also advantages within the framework of early disease recognition (Deininger and Käck 1999). González et al. (2008) identified, through automatic animal controls, short-term alterations in average feeding times of dairy cows, initiated through diseases such as ketosis or lameness. Even at that time, the authors suspected improved animal welfare, as well as economic advantages on the farm, through early recognition and treatment of diseases (González et al. 2008). Ettema and Østergaard (2006) investigated different causes of lameness with dairy cows and calculated, with the help of a model, the resultant costs in each case. Depending on lameness cause, costs between 178 € and 278 € per case were determined (Ettema and Østergaard 2006).

In general, sick animals could be isolated earlier through the system, some diseases identified and treated earlier, and the treatment period shortened. This could lead to a reduced number of vet visits, reduced application of medicine, a more rapid recovery of animals and, with that, less performance penalties. Additionally, earlier identification of infectious diseases can prevent, or at least reduce, infection spread to other animals (Madsen and Kristensen 2005, Cornou and Kristensen 2013, Geers 1994). With many diseases, early identification of altered animal behaviour is especially important in that the animal is passing on infection even before the clinical symptoms are apparent (Charleston et al. 2011). Saatkamp et al. (1997) investigated different identification systems with and without behavioural observation with pigs in relation to pig fever and the related economic effects. The annual financial loss could be reduced from 155 € to 38 € with the help of identification system with behavioural observation (Saatkamp et al. 1997). Through application of the system, or automatic recording of individual behaviour and deviations from this, not only costs could be saved but also animal welfare improved (Kashiha et al. 2013). However, not only diseases could be identified earlier, but also stress for animals could be reduced with the help of the technique (simultaneous recording of numerous transponder ear tags) for animals in the process of loading or driving, in that the animals in the group could be moved with no necessity of separating out individuals (Hammer et al. 2016, Stekeler et al. 2011).

However, to watch out for here on a farm where animal health is very good, is the probability that the benefit of the UHF system, and therefore also the saving potential, is substantially less than with a farm where the animal health status is poor. Where no, or hardly any, sick animals are identified in the herd, even a UHF system offers no additional benefit. For this reason, too, the so-called scenario technique was applied, in that the possibility of single results, with regard to cost savings (benefits) is unknown (Dabbert and Braun 2009). As a rule, a negative and a positive trend scenario is created, representing the most unfavourable and the most favourable development case. The 2, 5 and 10 % selected here seem to be practical and represent a relatively wide trend range, even if a benefit through the UHF system at the present time is unable to be guaranteed.

Efficient animal control

The daily control of every individual animal, especially with large farms, is particularly difficult and time consuming for the farmer to apply, although legally required (TierSchNutztV, 2014).

The wage rate for farmers (stockpersons) is approx. 17.50 € per hour (KTBL 2015e). For barn A this represents ≈ 3,500 €, for barn B ≈ 8,400 €, for barn C ≈ 3,728 € and for barn D ≈ 32,760 €, to be earned or paid for by the farmer, his family or hired labour.

Through the UHF-RFID system and appropriate software it would be possible to reduce the farm work time requirement in this respect. Imaginable would be a reduction in work time through faster identification of animal position in the barn. Animals appearing on an alarm list, e. g., those showing markedly altered drinking, feeding or movement behaviour, would be entered into the system with pen number or last-known position (e. g. antenna number) with present position in the barn able, therefore, to be found more quickly. The additional assistance of a handheld mobile reader would be practical here for large groups of pigs in that the electronic ear tags are difficult to read because of their small size, or have not an individual number but only a farm number printed. Through using a handheld reader, individual animals in a larger group can be easier to find. Also digital herd management, compared with written herd management, can be assumed to offer time savings in that the animals in question are permanently identified through the software and the actual ”condition“ of every animal in the herd can be called-up with a simple mouse click. Andres (2009) for example, described the manual documentation, data collection and input of data in Russian agricultural farms as especially time-consuming and open to doubt. Mainau et al. (2009) also described the value of an information system as time saving for staff. Time can be saved through such a system which otherwise would be required for data evaluation and behavioural studies.

Spreng and Auernhammer (2008) reported that a complex computer-supported feeding system for calves offers economic advantages for the farmer. As advantages of such a system, the authors identify reduced feed requirement, shortened rearing times, higher weight gain, less vet costs and savings in labour input and time.

In such benefit categories there also exists the problem of the great variation in farms and the ways in which they are managed. Additionally, the farmer in question has a conclusive influence on the possibilities for time saving. Hereby, own working speeds, technical affinity, technical understanding and motivation all play a decisive role, to mention only a few parameters. Because of these, it is difficult to determine exact information on time savings or labour cost savings. Thus, calculation of benefits regarding labour efficiency under different scenarios, as here, is more practical (Dabbert and Braun 2009). A farmer who already spends a lot of time in animal observation and control has possibly a lesser direct benefit through the UHF system compared with one that so far spends very little time even thinking about it.

Combination of inter and individual farm animal identification

The identification of fattening pigs with the farm number as well as visual, animal individual identification for dairy cattle with two ear tags, is mandatory (EC 2000, ViehVerkV 2015). This makes practical the connection of inter and individual animal identification for management reasons via ear tags.

Individual animal identification in fattening pig production is currently not yet standard. However, because of the current discussion on antibiotic application and animal welfare it is certainly possible that there will be a change in law in the direction of strengthened documentation of medicine application and animal welfare, as well as appropriate farm controls, in the coming years. In sow or dairy cattle management, there are already helpful applications such as pedometers, collars and/or electronic ear tags in the lower frequency range for determining walking behaviour, as access controls for concentrate feed dispensers, or in handling systems for movement of animals.

With the background of the system being fitted in a fattening pig farm, transponder ear tags with the farm number also printed would be practical, taking over the role of the mandatory farm number ear tag and thus reducing costs. But there is still no information available on loss rates for UHF ear tags with pigs, so required replacement expenses are not known. For this reason, monetary evaluation of ear tags with fattening pigs is omitted.

For dairy cattle, too, at least one of the two required visual ear tags could be replaced by an electronic ear tag. The costs for the electronic ear tag in this way are reduced by the costs for the visual ones and the purchase of further management aids (e. g. pedometers or collars) might also be avoided. In that the application, as well as the price, between these products vary greatly, a percentage reduction is calculated here too (Table 6).

Fertility management

With dairy cattle husbandry, in addition to the other benefit categories, there exists a further benefit in the area of fertility management. The economic efficiency of a dairy cattle farm is strongly influenced, as well as by feeding and a good herd health status, by good reproduction performance (Brehme et al. 2003). If the heat period of a cow is not identified, or noticed too late, this has a negative effect on milk production and the lifetime performance of the herd and, with that, a direct influence on the economic performance of the unit (Brehme et al. 2003). In larger dairy farms there exists often the problem of determining the optimal time for insemination of a cow, in that the precise observation of each cow is often impossible, as well as taking up a lot of time (Kohler et al. 2010). Investigations show that even experienced staff only recognise between 40 and 60 % of heat periods (Liu and Spahr 1993, Firk et al. 2002). Additionally, the movement, feeding and drinking behaviour of cows in heat and before calving, all change (Brehme et al. 2003, Raya 2011). All these parameters can be determined per cow with the help of UHF-RFID systems and therefore deviations from the standard recognised in good time. The optimum insemination period and calving date is in this way easier to determine and plan for. Compared with other systems of heat identification, such as heat ID plasters on cow backs, or a good visual behavioural monitoring of the animal by the farmer, the UHF technique identifies more rapidly any increased activity or alterations in animal behaviour.

In that the other, already mentioned, methods for heat identification are cheaper, the purchase of a UHF system for heat identification only should be avoided. In order to exploit synergy effects, UHF system purchase should be done where other uses, as mentioned above, can also be taken advantage of.

Non-monetarily assessable benefits

Alongside monetarily assessable benefit categories, non-monetary ones should also be observed. These can include increased work safety for stockpersons and improved animal welfare through simultaneous detection of animal groups. In German agriculture, the number of recorded accidents is much greater than those for all other sectors covered by the mandatory health and safety reporting system (Elsner von der Malsburg 2007). From the accidents registered in agriculture every eighth is through direct contact with cattle. From those, 12000 accidents occur, approx. 78 % through cows, 8 % through bulls and 6.9 % through calves (SVLFG 2014). The expected benefits in this relationship is based on the advantages of the UHF system compared with the so-far standardly applied LF-RFID animal identification systems. Through the greater reach and data transfer rates of UHF systems, animals can be identified from a greater distance (Kern 2006). Additionally, because of the greater data transfer rates, more transponders can be contacted and read at the same time (Kern 2006). Also under this system, there is no requirement for animals to be precisely run alongside the antennas of the reader. Singling of animals is no longer required, which means less stress for the animals, less danger for working personnel (Stekeler et al. 2011).

A further, non-monetarily evaluated benefit category involves advantages from the possibility of accessing data and information from individual animals. With the help of UHF transponder ear tags, animal individual data from all possible management areas, as well as additional parameters, can be read, documented and analysed. Additionally, movement behaviour, length of time spent in certain management areas, performance data and, with flow meter fitted drinkers, also animal individual water consumption are among the aspects that can be included (Junge 2015). Furthermore, individual animal based peculiarities, e. g. regarding disease susceptibility or genetics, can be stored on an animal individual basis and evaluated. Such recorded data and information can be used as observation and controlling instrument within the management of barns or farms. Such information can also serve as the basis for strategic individual animal based management and have a substantially positive effect on the farm business results.

Costs vs. benefits

The advantageousness of an information system can be assessed when the absolute benefits minus the costs give the net benefits presented per production unit (Table 7). The fundamental data come from the KTBL cost efficiency calculations for the appropriate production sector, management conditions and barn sizes (KTBL 2015e, KTBL 2015f, KTBL 2015g, KTBL 2015h, KTBL 2016). From the table, it is clear that only in dairy cow production in barn D with an assumed maximum net benefit could a slight positive result be achieved.

Table 7: Net benefits per production unit (kg slaughter weight or kg milk)

	Production unit in kg per animal place and year	Net benefits in € per animal place and year		Net benefits in €/kg	
		min.	max.	min.	max.
Barn A (400 pigs)	236.4	-21.6	-13.1	-0.09	-0.06
Barn B (1600 pigs)	262.7	-11.5	-6.6	-0.04	-0.03
Barn C (71 cows)	7,250	-92.8	-48.2	-0.013	-0.007
Barn D (624 cows)	8,500	-11.8	3.6	-0.0014	0.000

Because of the system, the farmer in fattening pig farm A and B has to, in the best case, do without 0.06 € and 0.03 € per kg slaughter weight. At a current price of 1.40 €/kg slaughter weight (LEL Schwäbisch Gmünd 2015), and with conventional production this, after all, represents a good 4 % (barn A) or 2 % (barn B) of total income per pig. Because of barn A's EC organic conformity (KTBL 2005e) the farmer here is able to sell the meat at a higher price. With a current price of 3.50 €/kg slaughter weight (LEL Schwäbisch-Gmünd 2015), the percentage proportion then is ≈ 1.7 %.

Only in barn D, in the best case, could costs per kg milk be balanced by benefits.

Once more it can be seen, however, that the material costs (in particular the costs for readers) as well as energy costs for the UHF system on the example farm described here are calculated as very high. Where the system is acceptable for practical conditions, substantial savings are to be expected, especially in this area so that rentability of the system, for all barns if required, can result. To achieve this rentability in all barns would have required, however, a cost reduction of 92 % in barn A, 87 % in barn B and 97 % in barn C. Only under these conditions would the monetary net benefits (in the benefit scenario 10 %) balance the resultant costs of the system.

Additionally, it has to be mentioned that the benefit categories such as work safety, simplified data management, reliability and flexibility are difficult, if not impossible, to assess – although these parameters can be of great importance for the farmer. In this way the benefits could already, even in the case of limited cost reduction of the system, be increased and a rentability of the system achieved.

Conclusions

Through comparing costs and benefits, advantageousness of the system could in conclusion be shown only for barn D under the highest benefit scenario. In that, however, the system is not yet in practical application, the calculation of costs was difficult with added costs created through the orientation on component development costs. Through the early stage of development, these lay in all probability higher than the costs for later end usage. Additionally, installation of the system in practical farming conditions would be different than described here in many individual cases. In particular, the number of UHF readers required could be reduced because, in practical application, readers with several antennas attached could be used. The readers represent a high percentage proportion of total costs. Thus, an overestimate of system costs can be assumed.

In that the benefits of the system are also hard to estimate, calculations incorporated percentage graduations of potential savings per benefit category which also appeared practical in retrospect because the very different parameters (farm structure, farmer, individual animals) could mean a benefit category having an especially positive, or a slightly positive, influence. Under the assumption that the system costs under practical application would possibly lie markedly under the costs calculated here, an advantageousness could also be expected for the other farms. Developments in the dairy cattle sector show that, despite higher costs, farmers are happy to invest in such systems (offering labour savings). In particular, installation of all animal identification systems with UHF (milking, feeding, heat identification, health) could represent a perspective for technologically-affinitive farms. In fattening pig production, rentability of such a system would be difficult to be achieved, even in the future. However, there can be an additional benefit within the framework of traceability programs and documentation of animal welfare indicators supporting quality marketing. For realising a first estimation of the system's costs and benefits, this work is logical and necessary. A renewed cost benefit analysis of market-ready UHF-RFID systems is to be encouraged in order to achieve conclusive and more precise results.

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