Recent Advances in Precision Livestock Farming

Abstract
Precision Livestock Farming (PLF) or SmartFarming is a new take on animal farming, similar to a management change in the ‘80s. At this time, firms started to employ employee motivation and the concept of the ‘firm as a family’ in order to make better firms. PLF is an attempt at making a similar change in animal farming: by detecting the needs of animals as early as possible and helping the farmers to satisfy those needs, animal wellbeing will increase. It is hoped that in turn this will increase socio-economic benefits of animal farming, i.e. make better farms.

Precision Livestock Farming\textsuperscript{1,2,3,4,5,6} was born in an attempt to help farmers cope with the challenges they are facing today. Modern livestock farming is expected to produce more and more to satisfy the growing intake of animal protein whilst at the same time increasing animal health and welfare, reducing energy use and environmental footprint and coping with fewer and fewer suitable workers for the farms. PLF is a reaction of the pressure from world market prices, causing farmers to focus on efficiency, large-scale production and automation, while still wanting to maintain animal welfare. PLF can offer different technologies to assist the farmer (e.g. surveillance systems to discover lameness) but also to improve the efficiency (e.g. optimise the feeding of the individual animal) and finally to reduce the labour cost or improve the flexibility at the farm (e.g. automatic milking systems).

Precision Livestock Farming has been around for some time but it has not yet fully lived up to expectations. There are many reasons, not least of which is the complexity of animals – as compared to plants and precision agriculture. Among the reasons why PLF has not yet become more widely accepted are the difficulties associated with making PLF technologies work reliably on commercial farms. Some are related to the suit-ability of the developed techniques and technologies. Others are related to a lack of education, awareness and training of farmers and consumers, coupled with the pursuit of PLF more as an academic discipline than a practical farming development platform. However, in many areas of the world the main reason behind the lack of adoption is that labour is cheap and available – although skilled labour is in short supply almost everywhere. The need for PLF is best understood when labour is short and expensive and where animal welfare is a consumer concern.

This contribution wishes to discuss obstacles to adoption of Precision Livestock Farming, as well as recent advances to overcome such obstacles. The main body of material comes from three EU-sponsored research projects, namely BrightAnimal, ALL-SMART-PIGS (www.all-smart-pigs.com) and EU-PLF (www.eu-PLF.eu).

What’s in a Name: SmartFarming, Precision Livestock Farming, iFarming
It was one of the conclusions of the ground-laying EU-funded project BrightAnimal\textsuperscript{7} that the term “Precision Livestock Farming” is not well chosen for marketing the subject to farmers and consumers. It was believed that the term suggests a field full of engineers rather than producers and marketing experts. As a consequence, neither farmers nor consumers are attracted to the field.

It was the impression that farmers think that PLF means “more time spent behind the computer rather than in the barn.” Although modern farmers in Europe – less so in Asia and Africa – understand and appreciate the value of management systems, they miss spending time with the animals. The term “precision” does not attract them.

Consumers on the other hand are very much removed in their thinking from modern farming. Pictures of animals running free on green grass very much dominate consumer thinking. Technology and animals don’t really go together in consumers’ minds.

As a consequence, it was felt that a new name was essential for the implementation of Precision Livestock Farming. The BrightAnimal group suggested the term “SmartFarming” or Smart Animal Farming\textsuperscript{7}. In a parallel effort, the company Fancom launched the name iFarming or Intelligent Farming. The name suggests that PLF allows farmers to use their intelligence to care for their animals and at the same time provide evidence for intelligent buying decisions by consumers. The name targets young, digital and entrepreneurial farmers that wish to act as trend setters and enjoy having full control over their production. Originally trademarked, the name has been released into the public domain in an attempt to make the brand available to all.

None of the names has yet found widespread adoption, but it is clear that Precision Livestock Farming refers more to the scientific field, whereas both SmartFarming and iFarming refer to the practical aspects of animal and farm-centric livestock production. In the following the terms will be used interchangeably.

What is PLF?
SmartFarming is an essential part of the “livestock revolution”\textsuperscript{8}, i.e. the necessary increase in productivity to cope with higher protein consumption and growing world population with limited resources, while maintaining the welfare of the animals.

SmartFarming has the obligation to contribute to providing solutions
• through an animal and farm-centric approach that seeks a balance between production, welfare and
SmartFarming is an essential part of European competitiveness and of Europe’s contribution to global food security.

BrightAnimal defined the essentials of SmartFarming as:

**Essentials of SmartFarming**
1. **Smart animal farming** is the approach to farming that aims to achieve economical, environmentally and socially sustainable farming through the observation, behavioural interpretation and control of the smallest possible group of animals.
2. Smart farming considers the bi-directional exchange of essential data and employs traceability for that purpose.
3. Smart farming is a discipline where farmers, engineers, biologists and economists work together to achieve the best possible results.
4. Smart animal farming has profound respect for the individual animal and tries to detect its needs in as timely a manner as possible.

**Main Obstacles to Adoption**
BrightAnimal concluded that there are a number of obstacles to adoption, such as:
1. Consistent marketing of PLF/SmartFarming/iFarming
2. Lack of direct cooperation between engineers, biologists, economists and farmers
3. Too much focus on sensing and too little on interpretation and control
4. Lack of a service sector with suitable business models
5. Technology aversion of consumers as a result of too large a distance between consumers and modern livestock farming
6. Consistent value-creation models on farm and in the feed-animal-food supply chain
7. Awareness and education

After having analysed these obstacles, the EU-sponsored project EU-PLF (www.eu-plf.eu) attempts to increase collaboration between engineers, biologists and economists through a large and well-balanced consortium. The EU-sponsored project ALL-SMART-PIGS (www.all-smart-pigs.com) uses the LivingLab methodology (www.enoll.eu) to increase collaboration between farmers, feed companies and slaughterhouses; see below. EU-PLF attempts to lay the basis for a future service sector in PLF by creating a validated blueprint (to be finalised in 2016). At the same time, the project validates the blueprint by creating spin-offs through a coaching and competition process. ALL-SMART-PIGS has dedicated some resources in collaboration with the EU-sponsored project CommNet (www.commnet.eu) and the British Nutrition Foundation to educating schoolchildren in modern livestock farming. EU-PLF is designing value-creation models both on farm and in the supply chain to address point 6. ALL-SMART-PIGS is conducting cost-benefit analysis in Smart Pig Farming on four farms (two in Spain, two in Hungary) in order to derive socio-economic value-creation models.

**Integration of Farmers and Other Stakeholders into the Development of SmartFarming Products**
The current challenge for SmartFarming is to penetrate the market (mainly farmers) with a set of new technologies and services. There are at least four key dimensions in industrial marketing (Webster, 1992):
1. Identifying customer needs, which requires understanding the economics of the customer’s operations, the structure of the industry within which they operate, and how they compete.
2. Selecting customer groups for emphasis, the classic problem of market segmentation, which takes on special meaning in industrial markets because of the high degree of buyer-seller interdependence after the sale.
3. Designing the product/service package, where there is seldom a standard product, the accompanying bundle of services is often more important than the product itself. Industrial marketing aims for improved profit performance, where sales volume and market share are not as important as in consumer marketing.

In ALL-SMART-PIGS we find the Living Lab (LL) methodology useful for accomplishing the needs for risk reduction and user acceptance in the efforts of bringing research and technology developments within PLF to a specific market – in this case European pig farmers. Each LL farm will act as an open innovation milieu, where innovations are developed by adopting a research-intense and stakeholder-driven approach. The focus lies on co-creation of innovations on the basis of users’ real needs and by involving the whole value chain.

Living Labs (LL) are currently heavily discussed in the European research community. Most of the discussions focus on open and publically available infrastructures to test and implement new products and services. Partners in the European Network of Open Living Labs (ENOLL) claim that there are a number of different models that can be used for LL collaborations. However, most LLs summarised in the ENOLL community depend on government and public funding and there is a clear lack of suitable alternative business models. In addition to European level harmonisation and definitions, there is now an emerging movement to tailor an LL concept for various user groups and application sectors.

The focus of each LL is:
- Continuous and open co-operation among different involved stakeholders
- Development of innovations based on user needs, desire and preference
This can only be obtained by:
- Engaging and empowering users to take an active part in
the creation of valuable innovations
- Interacting with users in their real-world context (i.e. on real farms)
- Correlating user involvement activities with ongoing research and social trends

The ALL-SMART-PIGS Living Lab process can be seen as a spiral in which the focus and shape of the design become clearer, while the attention of the evaluation broadens from a focus on concept and usability aspects to a holistic view on the use of the system. There are four iterative cycles that each consist of a repetition of three phases; see Figure 1.

The three repetitive phases in the ALL-SMART-PIGS Living Lab concept are:
- Appreciating opportunities (co-creation with users)
- Design (exploration and experimentation)
- Evaluation

These three phases (a-c) are repeated in four iterative cycles (1-4):
- Concept design
- Prototype design
- Final system design
- System demonstration

Figure 1 The iterative LivingLab process used in ALL-SMART-PIGS

In ALL-SMART-PIGS the above iterative process is used (i) to design a technology product/service package that appeals to European pig farmers and provides them with a clear value proposition, and (ii) to design and trial a traceability system with the purpose of preparing the development of a commercial offering at a subsequent stage. Given that the development of a commercial system for the exchange of data depends heavily on the acceptability, within the project we only attempt to collect first experiences with a limited number of players in order to better identify areas of value-creation.

Socio-economic Analysis of Smart Pig Farming
ALL-SMART-PIGS has set out to implement and evaluate five base SmartFarming technologies on four European pig farms (two in Spain, two in Hungary):

- Contactless weight measurement\(^{14}\)
- Dispensed feed per pen\(^{15}\)
- Cough index as indicator for respiratory health\(^{16,17}\)
- Activity and occupation index (distribution of animals within the pen and movements therein)
- Environmental parameters, such as ammonia concentration, temperature, humidity etc\(^{18}\)

In interviews with farmers it became apparent that not all value created by these technologies can be measured in pure economic gain. There is a combination of measurable economic gain, non-measurable economic gain and "soft value". Measurable economic gain refers to an impact of the technology that we know how to measure in money terms. Non-measurable economic gain is an area where there is a general agreement that value is created, but it is not yet clear how to measure it in money terms. An example would be early respiratory disease detection. Although economic gain for this can be modelled, it is very hard to measure on farm. "Soft values" refer to social values, such as satisfaction of workers that represent a value that cannot easily be measured in money terms.

In the project, we have conducted interviews with farmers after each fattening round using a standardised questionnaire where we collected economic farm data according to a simplified economic model of pig farms developed in the EU-PLF project\(^{13}\), qualitative data evaluating sense of control and detection of incidents (e.g. outbreak of disease) and soft values.

After farmer interviews and our analysis of farm data, it became clear that the continuous weighing of pigs using video analysis\(^{14}\) is the clearest case for measurable economic return. Measurable economic return stems mainly from a better detection of the ideal moment for slaughter, because (a) the weight growth curve slows down or (b) the ideal slaughter weight is reached within the precision of the measuring technology.

Figure 2 shows the price of a carcass as a function of its weight, from a real slaughter-house in Spain (blue line). Also shown is a first-order approximation of the benefit (red line); this approximation is not good for very large weights where it should be lower than shown.

Determination of ideal slaughter weight (around 85kg...
carcass weight for the above slaughterhouse) is subject to an error in estimating the weight. Particularly with narrower weight distributions (i.e. where most of the pigs have very similar weights), the precision is very important. If weight is determined incorrectly, the farmer suffers an opportunity loss and/or a price penalty at the slaughterhouse.

In Figure 3 (left) we show the optimal gain of one farm delivering to the above slaughterhouse as a function of the standard deviation of the pig weight. As can be seen clearly, a lower standard deviation leads to better financial results.

It is a known fact \(^\text{19}\) that several factors impact the width of the weight distribution, health issues being one of them. We are convinced that technologies such as respiratory health detection, activity measurements and feed dispensed measurements have the potential to demonstrate their measurable economic value from this curve. How-ever, it is still unclear how to isolate the impact of early warnings.

On the right hand side we show the savings per 1000 animals assuming that the PLF technology measures weight with 1kg error and the visual estimation of weight has an error of 5kg, as reported by farmers. The 1kg error is supported by on-farm measurements of the contactless weighing technology cited above.

It can clearly be seen that SmartFarming has an impact on those farms that attempt to optimise their returns – and at the same time wish to monitor welfare of the animals (which in Spain has currently little economic incentive). With 2.5 fattening rounds per year, a 1000-animal farm can improve its result by almost 9000€ per year, which certainly gives rise to an investment case for the weighing technology.

**PLF and Supply Chain Value-creation**

However, the ALL-SMART-PIGS project wanted to go one step beyond simple data capture and on-farm visualisation for more efficient management that normally is considered the focus of Precision Livestock Farming. The project explored the value of exchanging data using traceability between supply chain partners (see Figure 4), in particular between:

- Feed providers
- Farms
- Slaughterhouses/cutting rooms

Due to the lack of access to real data, feed manufacturers have to rely on test or re-search farms, farmers have to rely on experience and the offering of the feed industry, and slaughterhouses have little influence on the meat quality, with the exception of fines for off-spec animals. Given that even slight decreases of feed need make huge differences on micro and macro levels, the current approach is not optimal.

The starting point was our suggestion for a privately-run system where carcass composition data is made available to farmers for their individual animals. Farmers would then (via an electronic system) make averaged data available to the respective feed producers who can aggregate this data with that from other farms to judge the performance of their

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Figure 3 On the left, optimal gain per pig as a function of the standard deviation of the weight distribution. On the right, optimal savings per 1000 animals when using a PLF technology with 1kg error as opposed to visual estimation with about 5kg error.
Based on real and massive data, feed compositions\(^5\)\(^-\)\(^20\). Based on real and massive data, feed producers can on one hand optimise their products and on the other hand offer better products to individual farms.

The Danish Catellae System is an example where such an approach has been used, in this case for poultry. After some initial resistance, the system is now used by 100% of the Danish poultry farmers thanks to pressure by larger buyers, but also due to the optimisation potential that such a system allows\(^21\).

Through the open co-creation method described above, ALL-SMART-PIGS was able to confirm the value of such a feed-animal-food traceability system. In particular, the parameters shown in Table 1 have been considered to be of interest by feed companies, farmers and slaughterhouses.

This research is now being continued within the EU-PLF project and an economic evaluation of such information elements will be published in due time.

**Conclusions**

Technology uptake is increasing in all areas of humankind, and there is very little doubt that this will extend in the future to livestock farms. SmartFarming or iFarming is certainly the future of livestock farming, in particular since it addresses the balance between practicality (efficiency, economic return) and acceptability (concern for animal health and welfare).

Experience of installation of Smart Pig Farming technologies on commercial farms clearly shows that the technologies have to improve their robustness. Reliance on the internet for data transmission is a particularly tedious problem. Other more mundane problems include, for example, the depositing of fly faeces on camera lenses, which impacts weight and activity measurements.

There is a clearly measurable value in some technologies. In fattening animals the easiest directly measurable economic impact is related to determining the slaughter weight correctly and/or shortening the fattening period once growth flattens out.

However there are many SmartFarming technologies whose value is clear, but not yet directly quantifiable. Most of these have an impact on animal health and welfare, where the hard economics need to be substituted by softer values.

Further socio-economic research, currently being carried out in the EU-PLF project, will make value-creation on farm and in the supply chain more concrete. Models are under

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**Table 1 Validated concept for information exchange along the feed - animal - food chain**

<table>
<thead>
<tr>
<th>Feed provider to farmer</th>
<th>Purpose</th>
<th>Main data elements</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Historic cost of feed per kg of meat</td>
<td>Historic cost of feed per kg of meat</td>
<td>Feed identification (feed type, delivery identifier/date and a farm/silo)</td>
</tr>
<tr>
<td></td>
<td>• Target growth curve for service agreement</td>
<td>At beginning of fattening period growth curve (set of data points, potentially as a function of target start and end weights)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Service level (e.g. % protein, minimum % corn etc)</td>
<td>Updated nutritional profile per delivery</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Farmer to feed provider</th>
<th>Purpose</th>
<th>Main data elements</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manage changes in composition with respect to farm indicators such as weight gain and feed consumption</td>
<td>Per feed identifier (may require a link between pen and silo, for project we can assume one feed per farm) and per day</td>
<td>Number of pigs per pen over time</td>
</tr>
<tr>
<td></td>
<td>• Avg. weight (kg)</td>
<td>Avg. weight at day of production, weight variance, cough index, activity index, variance in lean meat % at end of cycle, mortality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Avg. feed dispensed per animal (kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Avg. activity index</td>
<td>Deliver to the system: weight gain at a particular age, incidences of respiratory diseases, variability of pig weight and lean meat %, activity indexes (under certain environmental conditions and/or feed composition), mortality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Avg. cough index</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Avg. effective temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Change in ammonia concentration with respect to 1-2 days before</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Farmer to slaughterhouse/cutting room</th>
<th>Purpose</th>
<th>Main data elements</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Understand the performance of the farm relative to peers (weight gain at a particular age, incidences of respiratory diseases, variability of pig weight and lean meat %, activity indexes (under certain environmental conditions and/or feed composition), mortality</td>
<td>Deliver to the system: weight gain at day of production, weight variance, cough index, activity index, variance in lean meat % at end of cycle, mortality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Time of last feeding</td>
<td>Receive from system: offset from average of the above indicators</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Genetics</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Feed type</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cough index</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Treatments</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Slaughterhouse/cutting room to farmer</th>
<th>Purpose</th>
<th>Main data elements</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight and composition data to optimise the feeding process</td>
<td>Per pig: live weight, carcass weight, carcass classification and lean meat %</td>
<td>Environmental conditions</td>
</tr>
<tr>
<td></td>
<td>Understanding non-compliances</td>
<td>Observations meat quality</td>
<td>Farm age</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Type of production systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Health problems before fattening (e.g. diarrhoea in piglet)</td>
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</table>

<table>
<thead>
<tr>
<th>Slaughterhouse/cutting room to feed provider</th>
<th>Purpose</th>
<th>Main data elements</th>
<th>Other data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight and composition data to optimise the feeding process (on average over farms)</td>
<td>Via farm: Avg. pig weight, carcass classification and lean meat %</td>
<td>Environmental conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Farm age</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Type of production systems</td>
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<td></td>
<td></td>
<td></td>
<td>Health problems before fattening (e.g. diarrhoea in piglet)</td>
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development that will allow a more direct cost-benefit calculation.

There is also clear value in the exchange of on-farm measurement data, in particular with feed companies. The main reasons for the interest are collected in Table 2.

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Main value creation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed provider</td>
<td>• Increase in feed quality</td>
</tr>
<tr>
<td></td>
<td>• Defence against quality claims</td>
</tr>
<tr>
<td>Farmer</td>
<td>• Increased control of the growth process</td>
</tr>
<tr>
<td></td>
<td>• Peer comparison</td>
</tr>
<tr>
<td>Slaughterhouse</td>
<td>• Increased control of delivered material</td>
</tr>
<tr>
<td></td>
<td>• Reduced meat quality risk</td>
</tr>
</tbody>
</table>

Table 2 Main value-creation potential as a function of the supply chain step

Acknowledgements

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8. ["A special report on feeding the world," The Economist, 24 February 2011.

Dr Heiner Lehr is a partner of Syntesa, a firm working in bringing innovation to the market. Heiner has been involved with Precision Livestock Farming since 2008. He was the co-ordinator of the ground-laying BrightAnimal project and continues his work now in the projects ALL-SMART-PIGS where Syntesa is the co-ordinator and in EU-PLF, where he leads the work packages on value creation and on spin-off creation. Email: heiner@syntesa.eu