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Development of the Production Module of an IoT Cloud Platform for Precision Livestock Farming

António Luís dos Santos Correia

Project Work presented as partial requirement for obtaining the Master's degree in Information Management

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DEVELOPMENT OF THE PRODUCTION MODULE OF AN IOT CLOUD PLATFORM FOR PRECISION LIVESTOCK FARMING

by

António Luís dos Santos Correia

Project Work report presented as partial requirement for obtaining the Master's degree in Information Management, with a specialization in Knowledge Management and Business Intelligence

Advisor: Professor Doctor Vítor Manuel Pereira Duarte dos Santos

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Dedicated to my children

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ABSTRACT

The agricultural livestock production sub-sector is characterized by its many geographically dispersed production points. Records are usually collected in handwritten forms that are then transposed to separate Excel sheets by technical assistants. These documents are used to evaluate "one-shot" results at the end of the animal production batches and are filed together with the other documents in the batch. Most of the collected data is usually not organized in a way that allows easy historical analysis and qualitative assessment of economic and technical results. Farmcontrol, the provider of an IoT solution for livestock farm monitoring wanted to somehow respond to current difficulties and add meaningful context to the enormous stream of sensor data that are generated. Its goal was to present relevant real-time insights to livestock producers while helping organize everyday farm tasks and benchmark results. To tackle this challenge Farmcontrol developed a new module for its cloud software that promoted the current work project.

KEYWORDS

Precision Livestock Farming; IoT; Cloud Software; Sustainable Agriculture

ACRONYMS

B2B	Business-to-Business
CEO	Chief Executive Officer
CTO	Chief Technology Officer
DB	Database
EU28	European Union (28 Countries)
FAO	Food and Agriculture Organization
IoT	Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
OECD	Organisation for Economic Co-operation and Development
PLF	Precision Livestock Farming
ROI	Return On Investment
UAT	User Acceptance Tests
UC	Use Cases

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1. INTRODUCTION

1.1. Background and Problem Identification

The OECD/FAO reports that world meat demand rose by about 20% over the last decade and that it is expected to grow by 15% in the next decade. Although global per-capita consumption is expected to decline by 3% (with the exceptions of India and China), the impact of population growth more than compensates that decline (OECD/FAO, 2018). As a result, livestock farmers have been submitted to a lot of pressure from global stakeholders in order to assure supply of animal origin products while guaranteeing a sustainable production process (Carvalho, 2010). In most developed countries, there is a growing concern that animals that are accepted to be used for food are treated with ethical care principles – mainly animal welfare concerns (Jochemsen, 2013).

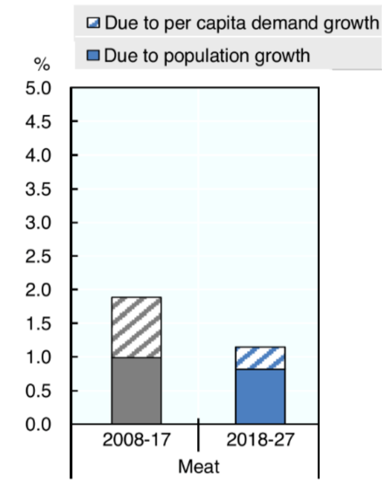

Figure 1 – Annual growth in Meat demand (OECD/FAO 2018)

Farmers were often associated with small-scale family productions that would supply their families and local communities. Nowadays this view has totally changed. To remain globally competitive, farmers need to have economies of scale in order to dilute fixed costs and be stronger against the volatility of global meat prices. Consequently, we are having fewer but larger farms around the world. This creates a difficult compromise: while farms are becoming larger, farmers still need to provide high quality, sustainable, and safe meat products – produce more with less. Farmers are having less time to care for individual animals while consumers expect individual attention and stronger relationships to each animal. Farmers need to assure good animal care to maintain productivity and be economically viable while being accepted by society (Guarino, Norton, Berckmans, Vranken, & Berckmans, 2017).

Livestock companies are being organized in groups, by mergers and acquisitions, forming larger projects that are more competitive but also more spread geographically, creating the urgent need for production information aggregation. Managers in these companies need to make sure animals in each farm are getting the best treatment possible to get the lowest production costs. Centralized controls and alarms are invaluable to getting the teams focused on the main cost drivers in animal production, especially in companies with higher employees rotation. The penetration of information technology on animal production made up until today was shy and slow but modern technology now makes it possible to use a variety of sensors to assist farmers' eyes and ears in everyday farming while following production performance. For example, book-keeping software that allows overall economic monitoring and feeding or climate automation that enables local control of on-farm processes (Guarino et al., 2017).

For reference, in EU28 countries, average farmer age is high: 68.2% of farmers are above 40 years old as opposed to only 57.6% on the general population (Eurostat, 2017). This brings the need to attract a younger generation of farmers that are usually more open to use technology tools to increase their work efficiency and provide better quality of life. Another challenge is education. It is reported that in EU28 only 8.9% of farmers have higher education (compared to general population's 33.9%) and 40.7% have lower education (compared to general population's 17.9%) (Eurostat, 2017). A less-educated farmer is more unlikely to explore new technology so education policies will be key to a faster adoption of these new tools.

The European Union is expected to promote digital farming, recognizing these technologies as a proper way to contribute to climate objectives. This means the deployment of an EU-wide investment plan targeted on new technologies via rural development programs. A good example is the IoF2020 project (www.iof2020.eu) that was subsidized by the European Union in 30 million euros to “accelerate adoption of IoT for securing sufficient, safe and healthy food and to strengthen competitiveness of farming and food chains in Europe”. The recent Animal Health Law (European Commission, 2016) prioritizes efforts in animal health and welfare surveillance. This is where precision livestock farming can greatly assist farmers and veterinarians in the future, enabling a more sustainable animal production (Guarino et al., 2017).

1.2. Farmcontrol Company & Value Proposition

Farmcontrol is an innovative solution aimed at the agricultural and livestock sector activities. It is a cloud-based solution that uses software, databases and browsers well established in the market as well as a custom open hardware solution.

The solution allows real-time measurement and control of most environmental and input variables of any livestock farming operation. It connects to most of the equipment installed on farms and gives the possibility of setting process automation rules. It allows the farmer to assess and improve animal feed, water and energy intake, which are critical to being cost effective in an even more competitive global market. This solution also tackles current environmental and animal welfare issues and constraints that will become even more compelling in the near future.

The Farmcontrol company started in 2013 and its products are now present on over 100 farms, mainly of pig and poultry production, in 5 different countries. Farmcontrol team’s set of skills meets the needs associated with project development because of their almost unique combined experience in software development, livestock production and business management. The main owners of the company are reference production companies with consolidated business knowledge of livestock production.

In 2017, the company became independent regarding its core cloud software solution, allowing the development of specific solutions to the livestock market and created a hardware-agnostic solution, paving the ground for multiple hardware integration. The development of a software API allows integration of other vendors software that will be key for future partnerships and client entry facilitation.

Farmcontrol Value Proposition

Farmcontrol is a hardware agnostic cloud-based software platform that integrates data from farm equipment connected through third party hardware solutions with human inputs and insights that can be collected in real-time to:

- Remotely access multiple geographically dispersed facilities;
- Prevent operational risks through custom alerts and notifications of critical situations;
- Increase production efficiency by creating optimal automated operational rules on key equipment;
- Monitor and benchmark main cost drivers in real-time;
- Comply with the latest animal welfare and environment requirements.

This project's value proposition allows the farmer to get multiple information in one place. Via the custom Farmcontrol Hardware Solutions, API or human input, the farmer can:

- *Increase Animal Welfare, Lower Costs*: collect valuable environment, energy, feed and water consumption data received from sensors in the rooms. Achieve basic animal welfare with stabilization of comfort temperature, homogeneous environmental quality that leads to mortality reduction and improved Feed Conversion Rate, which are key to lower production costs;
- *More Efficient, Less Ecological Footprint*: use the collected valuable data to be more efficient and save energy, feed and water;
- *Control Critical Equipment*: deploy custom automation rules to control windows, ventilation, lights, fridges or any other relevant equipment;
- *Manage Farm Events*: monitor manual or automated farm events with custom notifications. It is possible to get vital alerts on farm problems as soon as they occur and, at the same time, create manual events associated with batches;
- *Get Relevant Data Analytics*: analyse data with custom and dynamic chart reports and benchmark production goals;
- *Unlimited farms, Anywhere, 24/7*: Information of all production sites in one place enables our clients to optimize all their resources, from labour to maintenance needs.

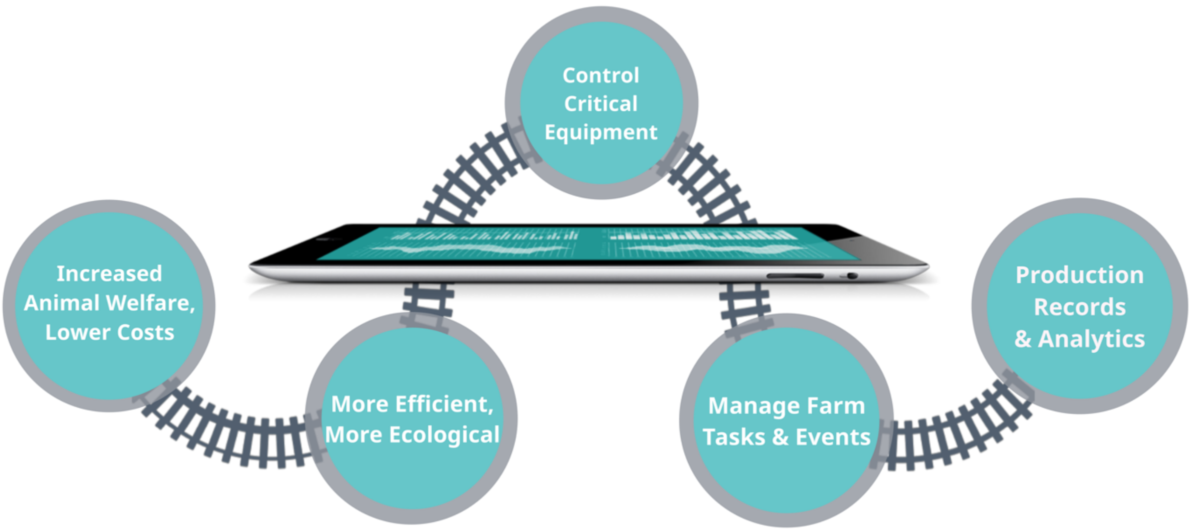

Figure 2 – Farmcontrol Value Proposition

1.3. Project Relevance and Goals

Although the company was well established in terms of offering a robust IoT solution for livestock farmers it lacked the collection of relevant daily production records that could provide meaningful context to the huge data streams generated by the thousands of sensors installed on its clients' farms.

The Farmcontrol software aims to evolve from an IoT technology enabler to a more complete actionable knowledge software provider for farmers. The project is highly innovative as current software solutions cannot balance traditional production record keeping with the real-time data collected by IoT sensors on farms. The project was born from a need presented by company's clients: most still relied on manual, unstructured records on farms that could not be summarized and evaluated systematically. The project is structural for Farmcontrol as it will allow the company to offer software-only solutions as a "point-of-entry" to its product line allowing the installation of hardware sensors if later required by the client. On the other hand, the collection of relevant additional data to sensor's records will pave the way for future data exploration projects and production of new business insights.

Farmcontrol wants to focus on real-time control on farms. This way, it should not attempt to replace traditional ERP systems that would introduce complexity at farm level (product code rigor, customer codes, stock management miscellaneous materials, purchase prices, etc.). The aim is to manage only the variables where the producer can have the available information quickly so that they can act and prevent economic costs. Current traditional systems only take a "snapshot" after the end of the production batch when any corrective measure can no longer be taken. Management is done in broader cycles of continuous improvement while a real-time control system allows for greater speed and efficiency. In addition, the system is a repository of production relevant information as well as a tool to allow greater coordination of teams through the task management module. Finally, the possibility of carrying out richer statistical and accumulated data analysis will increase the quality of the knowledge produced by the software.

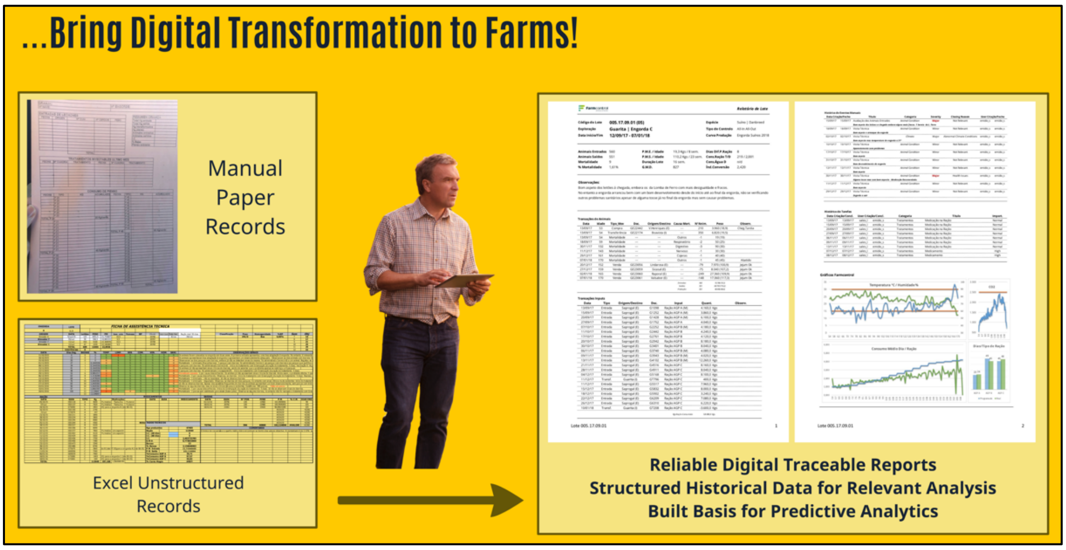

Figure 3 – Farmcontrol Digital Transformation Concept for Farmers

2. LITERATURE REVIEW

2.1. INTRODUCTION

Despite the solid professional background of company management, in order to define project priorities, a solid research project was essential to assure that the final product would have the most market acceptance.

The proposed work required a strong literature review on the following areas:

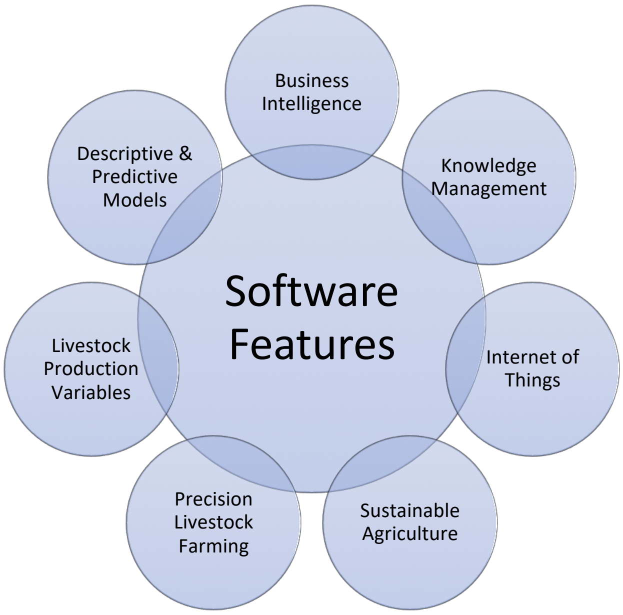

Figure 4 – Literature Review Structure

Below is a summary of each area's research goals:

- *Business Intelligence* – Research on the general best practices for the new software applications;
- *Knowledge Management* – Research on collective intelligence framework and possible application on livestock organizations team's task management;
- *Internet of Things* – Research on current business challenges;
- *Sustainable Livestock Production* – Analysis of the main concerns of producers and consumers regarding livestock production and the underlying need for a new software product regarding business and sustainability drivers;
- *Precision Livestock Farming* – Concept update and research on recent developments and challenges;
- *Livestock Production Variables* – Validate the relevant livestock production variables to monitor on the new software module;
- *Descriptive & Predictive Models* – Research examples of livestock production data mining to produce new descriptive and predictive algorithms for Precision Livestock Farming.

2.2. Business Intelligence

Decision Support Systems on Farms

Farmers are one of the oldest entrepreneur class and they are used to make decisions everyday based on intuition and past experience. At its core, Farmcontrol is a *decision support system* (DCS) that couples farmers experience and technology capability to improve the quality of decisions. DCS is a computer-based support system for management decision makers who deal with semi-structured problems (Keen & Scott-Morton, 1978).

At farm level, this means a monitoring system that measures compliance of production processes and drives the farmer to act as soon as possible to maximize production goals. The process can be described in three stages (Wolfert, Ge, Verdouw, & Bogaardt, 2017):

- *Sensing and monitoring:* measurement of actual performance of farm processes by sensors or manual human records. External data can be acquired to complement direct observations;
- *Analysis and decision-making*: compare measurements to set production performance goals and driving the farmer to decide on measures to correct any deviations that may occur;
- *Intervention*: Implementation of corrective measures to set farm performance on track.

Business Intelligence Architecture

A Business Intelligence standard architecture has the following components (Sharda, Delen, & Turban, 2018):

- *Data Warehouse* with source Data;
- *Business Analytics* – a collection of tools such as custom data tables, graphics, alerts, widgets for manipulating, mining, and analysing data in the DW;
- *User Interface* – (Providing Access Menus and Custom Dashboards);
- *Business Performance Management Tool* – for monitoring and analysing performance.

The process of BI is based on the transformation of data into information, then into decisions, and finally into actions (Sharda et al., 2018). Farm operations can dramatically change by accessing real-time data, forecasting and tracking physical items and increasing automation (Wolfert et al., 2017).

Farmcontrol software enables interactive real-time access to farm data. By analysing historical and current data from farms and benchmarking it with the set goals, decision makers get valuable insights that enable them to make more informed and better decisions. The new Production Module will provide a business performance management tool for monitoring livestock production batches.

Business Analytics

Business Analytics can usually be divided into three categories (Sharda et al., 2018):

- *Descriptive* (What happened? What is happening?)
- *Predictive* (What will happen? Why will it happen?)
- *Prescriptive* (What should I do? Why should I do it?)

As an IoT solution, Farmcontrol generates big data streams from farm sensors. Advanced Analytics applications will be necessary to manage this "fourth business revolution". Predictive modelling, smart adaptive systems, and self-governing processes are examples of how this may come to bear (Kottkamp, 2017). Predictive analytics can draw insights from patterns that human managers may easily miss, turning a tactical effort into a strategic initiative (Kranz, 2017) .

According to its current state of development, Farmcontrol can be characterized as a *descriptive analytics tool* because it provides real-time data from sensors on farms and/or human insights from farmers. The product will later evolve to the other two stages as the descriptive datasets will be mined for predictive/prescriptive algorithms.

Business Reporting

Usually data reports are presented in three forms (Sharda et al., 2018):

- Metric Management Reports
- Dashboard-type reports
- Balanced Scorecard-type reports

Before the implementation of the new production module, the Farmcontrol software provided only the first two types of report. Now it also provides detailed production batch reports that will present context-based metrics, by merging sensor data with human insights, and production records and benchmarking results with custom production goals. Farmcontrol reports use common descriptive statistics such as Mean (centrality measure) or Range (dispersion measure).

Information Dashboard

Dashboards provide a visual display of important data that is consolidated and arranged on a single screen so that information can be digested at a single glance and easily drilled in and further explored (Sharda et al., 2018).

Farmcontrol's dashboard is called "Farmview" and presents interactive real-time data from farms.

Business Intelligence Goals

Modern Business developments have pushed for the need of better decision support and analytics software tools (Sharda et al., 2018) that are driven by:

- *Group Communication and Collaboration* – Today we are living in a connected world where decisions are made by the collective collaboration of people who are usually dispersed geographically;
- *Improved Data Management*, combining varied data sources;
- *Managing Giant Data Warehouses and Big Data*, supporting larger data streams;
- *Analytical Support,* providing ways to quickly check risks and extract value from real-time data;
- *Overcoming cognitive limits in processing and storing information* by enabling computer systems to process large streams of data and extract relevant knowledge that otherwise would be impossible for humans to analyse efficiently;
- *Knowledge Management*, retaining relevant company structured information such as procedures or worker insights as well as unstructured communication data;
- *Anywhere, anytime support* – Mobile solutions are growing exponentially surpassing traditional desktop accesses. Users fully expect software to work in multi-platforms and be remotely accessible by mobile hardware.

Farmcontrol must address these challenges with the new production module by making real-time information easily transparent and accessible on the cloud.

2.3. Internet of Things

Defined by Cisco as "the intelligent connectivity of physical devices, driving massive gains in efficiency, business growth, and quality of life", the Internet of Things brought organizations an unprecedented opportunity to drive new sources of value — including the potential to automate up to 50 percent of manual processes (Noronha, Moriarty, O'Connell, & Villa, 2014).

Most of current IoT implementations are in the business-to-business (B2B) sector and focus on increasing production process efficiency by providing real-time information, for a faster business response, and data island consolidation (Kranz, 2017).

Although revolutionary, there are still challenges to be tackled in order to fulfil IoT's goals:

Data Quality

"IoT Is Not About Things – It's About Data" (Noronha et al., 2014). The current variety of connected devices, types of data and data sources makes data integration a larger challenge than ever before. Organizations also struggle to effectively integrate IoT data with other sources, such as third-party data providers from the cloud or internal data stores (Noronha et al., 2014). In addition, the number of connected objects are huge, and so are the issues related to representation, storage, interconnection, search and management of collected information (Mehta, Sahni, & Khanna, 2018).

For Big Data streams, which are often unstructured, the challenge is even bigger, and requires a strong collaboration between data scientists and domain experts (Wolfert et al., 2017).

The value of IoT will be bigger for those focusing on improving their data capabilities (integration, automation, and analysis) and overall process agility — not for those who simply connect the most devices to the network (Noronha et al., 2014). In the case of farmers, automated data analysis is needed to transform large amounts of data into useful information (Maselyne, Saeys, & Nuffel, 2013).

To fully leverage the IoT data automation and analytics, solutions must be tightly connected with business processes (keeping business need ahead of technology) as that will produce relevant data for business stakeholders (Kranz, 2017).

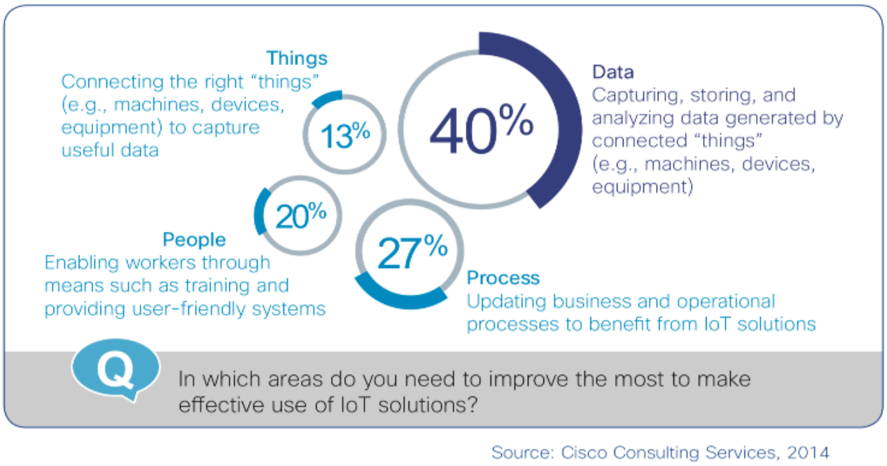

Figure 5 – Data relevance in IoT applications (Noronha et al., 2014)

Standards/Interoperability

The lack of interoperability standards in today's IoT solutions is creating vertical silos of architectures. It is imperative to address this or IoT may not achieve its goal related to flexibility, interoperability, concurrency, scalability, and addressability issues. (Ray, 2018).

Selecting one of the few interoperable solutions or even a cloud standard could free the system from underlying providers, but the system would still be locked into the particular solution that was selected. (Nogueira, Moreira, Lucrédio, Garcia, & Fortes, 2016).

The opening of platforms will accelerate solution development and innovation in general but also empower business stakeholders and create an attractive business model (Wolfert et al., 2017).

So, the two extreme ongoing scenarios are the proliferation of closed, proprietary systems tying the business user or open, collaborative systems in which every stakeholder in the chain network is flexible as to choosing business partners and production technology. The further development of data and application infrastructures (platforms and standards) and their institutional embedment will play a crucial role in the battle between these scenarios (Wolfert et al., 2017).

Security/Privacy Issues

IoT should be built on a strong security base, adopting rigid unified policies with automated , risk-based self-defence and self-healing capabilities (Kranz, 2017).

Organizations need to address privacy issues of employees or clients made aware by IoT solutions. Privacy policies should be transparent and clear in order to avoid the collection of unwanted private data (Kranz, 2017). Blockchain has emerged as a technology that allows a secure exchange of value between entities in a distributed fashion by maintaining a continuously growing list of data records that are protected from tampering and revision (Kranz, 2017). Data-ownership, privacy and security issues have to be properly addressed, because too strict policies can also slow down innovation so a right balance should be obtained (Wolfert et al., 2017).

Data location is becoming an issue in today's globalized businesses. Where data reside — both physically and geographically — is a big issue for companies and even governments. All IoT solutions should know whether data is crossing international borders and whether different rules should apply to such movements (Kranz, 2017).

Organizational/Cultural Change

As IoT solutions are so intertwined with business processes, both IT and Operational Managers should recognize the need to share responsibility for IoT projects even if decision authority has to be negotiated over each stage in the adoption process. Success requires this effective teaming and, of course, new workforce skills (Noronha et al., 2014).

Change Management is key as operations must be rethought from the ground up. When everything is digitized and can communicate with everything else, business managers must find new ways to do things faster or cheaper and more efficiently and effectively. (Kranz, 2017).

Even if there is initial resistance to change by employees, the increased productive time on the job (due to efficient information delivery) and the reduced work travel time (due to remote monitoring) should convince them soon enough (Kranz, 2017). As people are more and more attached to their mobile devices, solutions must be always readily available there (Kranz, 2017)**.**

2.4. Knowledge Management

The arrival of the digital age made available new electronic collaboration tools that allow groups of people to tackle common tasks in a collective way even when not knowing each other or being on the same space or time. It's the dawning of a new "Collective Intelligence" age (Malone, Laubacher, & Dellarocas, 2010). The working definition of collective intelligence is "groups of individuals doing things collectively that seem intelligent" (Pentland, 2006).

Google, Wikipedia, Linux and Threadless are living proofs that companies can start to use technology as a way to motivate users to contribute to business value creation in a cheap and easy way. But companies still need to deeply understand the scientific basis of these tools and the framework needed to apply the concepts to business cases. The simpler approach is usually used to describe business (the design questions What?, Who?, Why? and How?) and to classify the "building blocks" or "genes", which in turn, after being combined in a useful way, will form the "genome" of "Collective Intelligence Systems." Chaotic collaborative creation processes (the create "gene") always need to have decision processes in place (the decide "gene"). The following figure represents a 16 "gene" representation of the proposed "genome" (Malone et al., 2010):

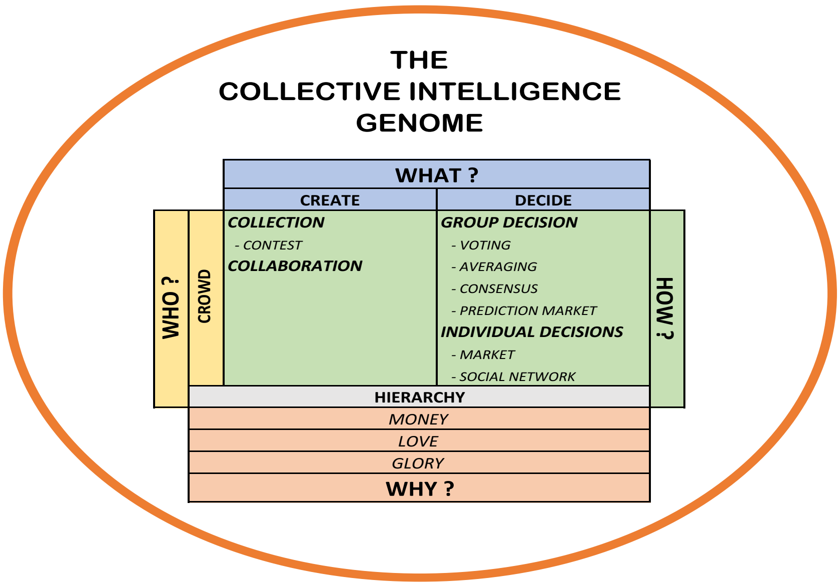

Figure 6 – Representation of the Collective Intelligence Genome

(inspired on Malone, 2010)

Although simple, in principle, in order to enable a crowd-enabled collective intelligence process we must divide the main goal in smaller activities and assure that crowd contributors make positive non-destructive contributions to the system. The "Why?" gene and the careful elaboration of its motivation drivers is also key for process success. In the case of farmer organizations, we can define *Collaboration* as the "create" gene (when the contributions have important dependences between them that must be managed accordingly by some kind of decision process gene). The "decide" genes are a combination of *Group Decision* (through voting) and hierarchical decision for final approval and classification. After this knowledge validation process is complete, the directors or any user can incorporate the tasks on their daily work processes. These kind of systems force organizations to promote change and inspire workers to give their best, because knowledge around existing practices can create a form of 'lock-in' where a significant advantage is needed to induce sustained change to any new practice (Eastwood, Trotter, & Scott, 2013).

This is only a starting point, as the combination of "genes" to form a successful "Collective Intelligence Genome" and its potential applications are endless. Using "crowds" for "love and glory" is a very cheap way to achieve a big goal, but this process can lead to an uncontrolled free contribution process that can backfire to the enablers. So, starting a new collective intelligence project is an exciting and limitless experience, but also one that should be carefully prepared. It should involve a thoughtful framework to achieve meaningful "intelligent" knowledge and not just a lot of "noise" ideas or a lot of good ideas that cannot be managed effectively (Malone et al., 2010). In addition to the basic ingredients of member skills, collective intelligence is enabled by the group interactions that combine those skills to good effect. In other words, groups in which one or two people dominated the activity were, in general, less collectively intelligent than those in which the activity was more equally spread among group members (Woolley, Aggarwal, & Malone, 2015).

2.5. Sustainable Livestock Production

Today's livestock production must combine several requirements such as:

- Guaranteed food safety and quality
- Improved animal welfare and health
- Reduced environment impact
- Improved sustainability and efficiency

Sustainable agriculture is the efficient production of safe, high-quality agricultural products, in a way that protects and improves the natural environment, the social and economic conditions of farmers, their employees and local communities, and safeguards the health and welfare of all farmed species. Given this concept, the definition of sustainable livestock requires a holistic and cross-sector approach (Livestock, 2017). On developed countries such as the EU, livestock farmers are more conscious about keeping animals for food production: they should be raised, treated, and slaughtered in a more animal-friendly way and should have a life worth living (Guarino et al., 2017).

Figure 7 – Sustainable Livestock Representation (EU40, 2017)

Traceability and Production Records

Traceability is about knowing where a food item is or has been at a particular moment and what has been done to it (Sooksmarn & Kokin, 2010). In livestock production this translates to general good record keeping, following the inputs and outputs through each production stage and from company to company. It is, however, not enough to follow the material and information flow in order to ensure human health. It is key that traceability information is always readily available for consumers that want to be able to drill down into data (e.g. production sustainability, fair trade prices and certification data) or Public health authorities that need immediate access to consolidated data in case of a food crisis (Sooksmarn & Kokin, 2010). There is also a growing pressure for a decreased use of antibiotics to limit the impact of animal farming on human health by reducing antimicrobial resistance (AMR) (Tomas Norton & Berckmans, 2018). Traceability is also key to reduce illegal trading of livestock products (Banhazi et al., 2012).

Expected results of strong and transparent traceability systems include an increased consumer trust in meat production, improved communication on animal welfare and health, shared information among supply-chain partners to optimise business processes, verification of meat quality, increased margins for high-quality products and improved environmental performance (e.g. energy consumption, waste creation) (Hoste, Suh, & Kortstee, 2017).

Integrating traceability with PLF (*Precision Livestock Farming*) systems improves its usefulness (Banhazi et al., 2012). The information collected by PLF serves tracking and tracing opportunities in a transparent quality control of the whole chain of custody from farming to retail (Scholten, De Boer, Gremmen, & Lokhorst, 2013).

Currently, for pig production, the information used as a basis for decision making is a combination of observations of the animals and their environment, as well as production results, which are typically reported monthly or quarterly. The adding of sensor technology can provide more objective and reliable data in this context. Integrated monitoring systems can combine the strengths of the stockman and the computer-based system (Cornou & Kristensen, 2013).

We can add that, especially in the livestock sector, there are usually manual records on paper and PLF technologies can help the migration to digital records with increased reliability and usefulness.

Animal Welfare

Welfare has to do with the animal being in harmony with its environment (Broom, 2017). The concept was introduced in 1965 by the Brambell commission (Brambell, 1965) and can be summarized by the five "freedoms" concept:

- Freedom from Hunger and Thirst
- Freedom from discomfort
- Freedom from Pain and Diseases
- Freedom to express natural behaviour
- Freedom from fear, stress & anxiety

Poor animal welfare is the reason consumers have been considering some livestock production systems as unacceptable, sometimes refusing to buy products, because animal welfare has become a quality requirement. While challenging, this brings an opportunity for sustainable production farmers to better market their products. Official policies, mainly led by EU, have been answering this overall sentiment by implementing even stricter welfare laws. Improving animal welfare is believed to contribute to better overall welfare and that has an impact on humans as well (Broom, 2017). One example is the recent fears that pandemic animal diseases could be transposed to humans (Guarino et al., 2017). Precision Livestock Systems are invaluable tools for improving or at least objectively document animal welfare on farms (Banhazi et al., 2012).

Recent studies demonstrate that the attitude of farmers with respect to animal welfare is always positive. Farmers see welfare and health as important factors of their production that greatly determine their productivity and income. However, they made it clear that welfare measures without regard to economics are unrealistic (Hartung, Banhazi, Vranken, & Guarino, 2017).

Environmental Impact

Livestock production is, on government official policies, targeted as potentially very pollutant. We need more animal products with less feed generating, less nature resources consumption and less manure and emissions. Healthier animals drink less water and even avoidance of stress on animals contributes to improve metabolic energy production. Therefore, by improving animal welfare we can improve production process sustainability (Tomas Norton & Berckmans, 2018). Precision Livestock Systems offer relevant tools to reduce greenhouse gas emissions and improve environmental performance of farms (Banhazi et al., 2012).

Current Major Environmental Challenges are (Animal Task Force, 2017):

- *Greenhouse gases*: Livestock accounts for 40% of global agricultural emissions;
- *Air quality*: Livestock accounts for 90% of ammonia emissions;
- *Soils*: Livestock impact vary according to soil use. The most positive effects are linked to grasslands, the most negative effects result from high animal densities;
- *Water quality*: In high animal density areas, nitrogen and phosphorous leaching and runoff contributes to the eutrophication of waterways, deterioration of water quality and an increase in water treatment costs. The EU has placed a strong emphasis on monitoring and reducing nutrient loading from effluents (the Nitrates Directive);
- *Biodiversity*: The positive effects of livestock farming on biodiversity are associated with the use of permanent grasslands and upland areas, environments rich in floral and faunal diversity that would afforest or close over in the absence of livestock grazing. The negative effects are the loss of permanent grasslands and increased fertilizer use contributing to reduced plant diversity levels and the sharp reduction of biodiversity in domestic livestock species.

The approach of leading European meat companies

It is interesting to see what big meat production companies in Europe are communicating about sustainable livestock production. We selected two relevant examples, Tonnies Fleisch – the 7th pig meat processor in the world (Plantz, 2016) and the VanDrie Group, world leader in veal meat (source: www.vandriegroup.com):

Tonnies Fleisch (www.toennies.com), Germany, 6.9 Billion€ Sales (2017)

VanDrie Group (www.vandriegroup.com), Holland, 2.2 Billion€ Sales (2017)

TÖNNIES VanDrie Group

Tonnies/VanDrie Vision of Sustainable Livestock Production

Guaranteed food safety and quality
"Commitment to chain-wide system for the improvement of food safety, quality and animal health" (Tonnies, 2017)
"Project Antibiotic free Fattening" (Tonnies, 2017)
"Reducing the use of antibiotics" (VanDrie, 2017)
"Self-control of all quality important parameters" (Tonnies, 2017)
"Guarantee salmonella-free raw material" (Tonnies, 2017)
"Guarantee meat quality by controlling the cold-chain compliance" (Tonnies, 2017)
"Guarantee Meat tenderness and meat quality" (Tonnies, 2017)
"Traceability from stable to plate. F-Trace own initiative for consumers to trace back products on stores" (Tonnies, 2017)
"Make the process of our production transparent. We want to show how we work" (VanDrie, 2017)
Improved animal welfare and health
"Promote scientifically based improvement of animal welfare" (Tonnies, 2017)
"further development of friendly animal systems" (Tonnies, 2017)
"Animal Welfare at the slaughterhouse" (Tonnies, 2017)
Reduced environment impact
"Reduce Livestock environment footprint" (VanDrie, 2017)
Improved sustainability and efficiency
"Develop more sustainable hybrid meat products" (VanDrie, 2017)

Source: Group Tonnies/VanDrie company presentations at Animal Task Force Seminar on Food Integrity, Brussels 26/10/2017

Figure 8 – The vision of two European companies on Sustainable Livestock Production

As can be seen, large meat companies are aligned with the sustainable livestock production drivers. This is not only due to legislative pressure, but mainly due to the pressure of public opinion on leading brands for sustainable products.

As a negative example and a sample of non-compliance impact of an animal welfare crisis, we have the case of a big Spanish meat company called EL POZO (www.elpozo.com). In 2018, the company was involved in an animal welfare scandal on one of its suppliers' farms largely publicized by the media. The result was very damaging on the company's image with direct impact on sales, as proven by the following news:


http://www.expansion.com/empresas/distribucion/2018/02/12/5a81e0e222601d243c8b4657.html

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Dos cadenas de supermercados belgas suspenden las compras a El Pozo

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Figure 9 – News Article about El Pozo following an animal welfare scandal

"Two Belgian supermarket chains suspend purchases to El Pozo"
(link:http://www.expansion.com/empresas/distribucion/2018/02/12/5a81e0e222601d243c8b4657.html)

13-02-2018

By these three examples we acknowledge that the meat processing sector is an extremely sensitive business activity. Consumers expect to be offered attractively priced, safe and high-quality meat products. Replacement of the traditional and local small-scale production with mass production can lead to resistance from consumers even with lower prices. On the other hand, the meat processing sector is characterized by capital shortages and low profitability, but still needs to present sustainable products (otherwise it will risk consumer rejection). These financial hurdles are pushing the meat business sector to concentrate by consolidations, mergers or takeovers creating larger groups of companies that, although needed, may displease the consumer (Pawlonka, 2017).

2.6. Precision Livestock Farming

Precision Livestock Farming Concepts

Today's *PLF business models* can be divided in four categories (Guarino et al., 2017):

- *PLF as a sensor* – An entry phase, just the collection of data by telemetries, sensor technologies and deductive tracers (Scholten et al., 2013);
- *Early warning with PLF technology* – Coupled with sensors where there is an early warning tool that analyses sensor data and produces alarms, usually generated by predictive algorithms;
- *Process optimization with PLF technology*- Sensor and early warning tools are complemented by production reports that are used for on-farm process optimization. These farm reports are usually aligning data with production goals and comparing data from different farms and/or different date intervals;
- *Continuous consultancy and benchmarking of PLF data* - meta-data analysis is added to the system, usually by collecting relevant manual data and insights from the farmer or veterinary on a daily basis and combining other data sources (e.g. market prices) in order to provide more accurate insights to the farmer, sometimes with the help of an online professional consultant.

PLF is a developing technology tool for online, continuous and automatic monitoring of animals (Guarino et al., 2017). PLF is a reaction to the pressure from world market prices, causing farmers to focus on efficiency, large-scale production and automation, while still wanting to maintain animal welfare (Lehr, 2014). PLF assists farmers by reporting the status of animals and their environment and helps them make quick and evidence-based decisions to adjust to changes in animal requirements, health, and behaviour (Guarino et al., 2017). PLF technologies provide methods for electronic measure of critical system components that indicate resource use efficiency, a software to interpret collected information and control of processes to ensure optimal resource use efficiency and animal productivity (Banhazi & Black, 2009). This enables dramatic production efficiency gains for livestock enterprises, as these new technological tools improve on the traditional approach that is just fine-tuning existing animal production methods (Banhazi & Black, 2009). PLF presents itself as having many advantages, both for the environment and for increasing productivity: The efficient use of increasingly scarce natural resources and inputs, the reduction of uncertainty on the part of producers in decision making and management processes, and the contribution to people and animal safety and well-being (Carvalho, 2010).

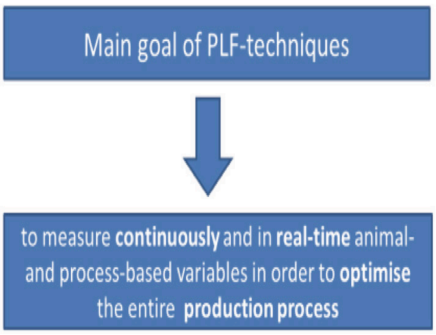


Figure 10 – Main goal of PLF-techniques (Guarino et al., 2017)

Enabling real-time management is core to PLF. This approach is what helps secure improved health, welfare, and yields as well as reduced environmental impact. In fact, this real-time aspect and being part of the management system is what makes PLF quite different from other solutions. Unlike other common business indicators that are usually retrospective, PLF aims to help and adapt the process management on the spot and in real time for the animal that is followed continuously during the production process and warn the farmer immediately (Guarino et al., 2017). Farmers get a warning when something goes wrong in such a way that the PLF system brings them to the animal(s) that need their attention at that moment (Daniel Berckmans, 2017).

The increased scale of livestock facilities makes it difficult for farmers to monitor animals by observing and interacting with individuals and make farming decisions based on experience and historical knowledge about the particular animals. PLF tools help manage this by establishing priorities and alerts for the farmer to know which particular animal or group of animals requires their attention (Guarino et al., 2017). Timely detection, solving and treating disease and welfare problems of individual pigs can prevent decreased health, decreased growth and economic losses (Maselyne et al., 2013).

Individual electronic identification is used in many PLF applications. This equipment makes accurate data collection more likely to occur as it is easier and more labour efficient, although it does not allow a producer to achieve anything that cannot be completed manually (Eastwood et al., 2013).

Although PLF is increasingly relevant, the biological process is just far too complex to completely replace farmers with technology. This technology will offer more possibilities for the farmer to be more efficient, improve working conditions and get a monitoring and management system to better approach the genetic potential of today's livestock species (Daniel Berckmans, 2017). Some studies identify the need for farmers to see the animals directly (and not only by video, for example) for concerns about not paying enough attention to the animals and losing contact with them. The PLF industry must make clear that PLF is a valuable help and the farmer's time saved should be invested in better animal care (Hartung et al., 2017). PLF should not pretend to erode the personal, attentive relationship of the farmer with the animals which is the core of its identity (Werkheiser, 2018). Further work is required to integrate technologies with the expertise of the farmer, thereby adopting a "farmer-in-the-loop" approach to PLF development (Exadaktylos & Berckmans, 2016).

PLF applications are expected to reduce labour cost and increase the efficiency and reliability of working activities (Banhazi & Black, 2009). The need for PLF is best understood in developed countries where skilled labour is in short supply and expensive and consumer concern for animal welfare is high (Lehr, 2014).

Current challenges of Precision Livestock Farming

Bioethics issues – PLF is at risk of being seen as technology that encourages the instrumental use of animals and a possible compromise of their well-being (Carvalho, 2010; Wathes, Kristensen, Aerts, & Berckmans, 2008). Sometimes consumers experience technology aversion as a result of too large of a distance between consumers and modern livestock farming (Lehr, 2014). There is the risk that PLF facilitates the creation of even larger farms, prioritize value of rapid weight growth instead of typical animal behaviour or prioritize profit over environment. Another issue is the loss of farm jobs and the ''de-skilling'' of those that remain. Finally, there is also the broader issue of animal-derived product consumption. How these issues are reconciled is a longstanding ethical problem (Werkheiser, 2018).

Technological Challenges – Enabling robust, low-cost sensing systems (Chastant-Maillard & Saint-Dizier, 2016) and providing data-based models with meaningful parameters for the farmer (Wathes et al., 2008). The information provided should therefore be relevant and in real time, if it is to be used for improving productivity, health and welfare (Cornou & Kristensen, 2013). There is too much focus on sensing and too little on interpretation and control (Lehr, 2014).

Convince farmers of the ROI of PLF solutions – There should be a clear demonstration of the increase in biological goals valued by the farmer (Carvalho, 2010) and proper marketing strategy to promote farmers' confidence (Lehr, 2014; Wathes et al., 2008). There is currently a gap between the potential perceived by precision technology developers and the on-farm benefits achieved by farmers (Eastwood et al., 2013; Hartung et al., 2017). The benefits of PLF need to be demonstrated and publicized (Banhazi et al., 2012) in order to avoid the usual negative associations of PLF with high prices, complicated operation, and slow maintenance service (Hartung et al., 2017). Some studies suggest farmers are afraid that the market does not pay their investments back, that is the feeling of being left alone with new technology and a lot of legal regulations (Hartung et al., 2017).

Demonstration of additional socio-economic improvements – such as improved working conditions (less working hours, better physical working conditions), increased pride and social recognition of farmers, attraction of younger generations into the farming business, increased attractiveness to external investors (Lokhorst et al., 2012).

Cooperation Efforts – PLF unites many complementary fields such as the farm animal sciences in health, nutrition and ethology with bioengineering, computer science and socioeconomics. This complementarity is absolutely essential to realise technologies that can monitor and help manage individual animals for their own benefit (health and welfare) as well as for the benefit of the farmer, community and environment. By promoting such scientific collaborations we can provide trustworthy systems and avoid problems of mistrust by consumers (Tomas Norton & Berckmans, 2018).

Creating a Service Sector with suitable business models and consistent value creation in the feed-animal-food supply chain (Lehr, 2014).

Education and awareness of farmers to cope with new technologies (Lehr, 2014). Farmers are open to change but need objective and qualified help to be able to run new systems (Hartung et al., 2017). Training is a necessity when it comes to the efficient use of PLF.

Data Ownership – individual data should be owned by farmers, but ownership over aggregate data needs to be clarified. As this data is valuable, it is imperative to define who profits from it and whether fair value is provided to farmers (Exadaktylos & Berckmans, 2016).

Effective and Attractive Data Analytics – The graphical presentation of sensor data alone does not seem to be enough for farmers. Additional information by sensor combinations, key production indices and the potential for early warning provide an addition to current practice. Presenting attractive user interfaces for the correct visualisation of PLF data are also critical to bring more added value compared to the plain use of the technology (Van Hertem et al., 2017).

2.7. MAIN LIVESTOCK PRODUCTION VARIABLES

Many variables need to be monitored during the production process at the animal, farm, and food chain level (Guarino et al., 2017). Farmers usually rely on their experience, animal observation and judgment. However, with the increased scale of farms and corresponding higher number of animals, it is more difficult to have an effective control. It is also impossible for the farmer to monitor the animals continuously, 24-h a day, and that is where Precision Livestock Farming can help (Guarino et al., 2017). Mainly because early detection of health and welfare problems is essential to enhance animal treatment success, increase animal welfare and promote sustainable production (Matthews, Miller, Clapp, Plötz, & Kyriazakis, 2016). Successful management of livestock herds consists in combining information on individual animals with feed composition, environmental conditions and management routines in order to achieve optimal productivity, welfare and health while simultaneously avoiding over-feeding and feed wastage (Lokhorst et al., 2012).

The following selection of variables is key to understanding and implementing the main priorities of control and characterization of Livestock Production Batches and producing relevant actionable knowledge for farmers with the new software features:

Production Batch Variables

These aspects are the main priorities for European Producers regarding Precision Livestock Farming Systems: A recent survey to European Farmers showed that they were very much in favour of integrated surveillance and monitoring systems for growth rate, feed conversion, feed and water consumption, climate control, and health monitoring (Hartung et al., 2017).

- *Initial Data* – initial production batch characteristics regarding animal management decisions, genetic breeds used, production season that can influence production results at the end of the batch (Stygar, Dolecheck, & Kristensen, 2018);
- *Ambient/Living Conditions* – Climate represents one of the main limiting factors of production efficiency. Thermal stress events can cause reduced performance, morbidity, and mortality, resulting in significant economic losses and animal welfare concerns (Laberge & Rousseau, 2017);
- *Feed Program* – Providing animals with an adequate feed supply is a key aspect of livestock production systems. Its effectiveness is not only related to the quantitative and qualitative aspects of diet, but also to the physical environment and social context of feeding activity (Averós et al., 2012);
- *Water Consumption* – Water usage relates to important variables such as indoor temperature, food intake, food conversion, growth rate and health condition (Brumm, 2006; Kashiha et al., 2013; Stygar et al., 2018). So, water is a key indicator for automatic monitoring of pigs health or productivity status (Kashiha et al., 2013). With sophisticated methods and algorithms, other predictors of performance may be developed depending on the patterns detected (Brumm, 2006);
- *Medication Programs* – One of the major production costs (Hartung et al., 2017) and a key indicator of animal health and food safety;

Production Batch Variables Table

Dimension	Metrics	Authors
Farm *(Initial Data)*	Farm ID (In order to connect with Farm Metadata Variables)	(Douglas, Szyszka, Stoddart, Edwards, & Kyriazakis, 2015; Silva et al., 2017)
Gender *(Initial Data)*	Gender (Male, Castrated Male, Female, Mixed)	(Douglas et al., 2015; Silva et al., 2017)
	Gender segregation in pens (Yes/No)	(Douglas et al., 2015; Silva et al., 2017)
Origin *(Initial Data)*	Origin/Origin Type (Piglets Units, Farrowing-to-finish units)	(Silva et al., 2017)
	Number of Pig Origins	(Pierozan et al., 2016)
Genetics *(Initial Data)*	Genetic Breeds (Large White (LW)/Landrace (L), LW/L×Duroc (D) or purebred D, LW/L× Pietrain (P) or purebred P, LW/L× Hampshire, LW/L×D× P)	(Douglas et al., 2015; Silva et al., 2017)
Density *(Initial Data)*	Number of animals entered	(Van Hertem et al., 2017)
	Stocking density (animals/m^2 in the barn)	(Van Hyfte et al., 2015)
Seasonality *(Initial Data)*	Season (Winter/Autumn, Summer/Spring, Both)	(Douglas et al., 2015; Silva et al., 2017)
Medication Program *(continuous measurement)*	Medication Inputs and ID	(Banhazi & Black, 2009)
	Use of Antibiotics (Yes/No)	(Guarino et al., 2017; Silva et al., 2017)
	Number of animals treated with medication	(Van Hyfte et al., 2015)
Water *(continuous measurement)*	Average Daily Water Consumption (l/day)	(Van Hertem et al., 2017)

Table 1 – Production Batch Variables

Production Batch Variables Table (continued)

Dimension	Metrics	Authors
Feed Program *(continuous measurement)*	Feed Inputs and ID	(Banhazi & Black, 2009)
	Average Daily Feed Consumption (Kg/day)	(Banhazi & Black, 2009; Douglas et al., 2015; Van Hertem et al., 2017)
	Crude fibre (g/kg)	(Douglas et al., 2015)
	Crude Protein (g/kg)	(Douglas et al., 2015)
	Lysine (g/kg)	(Douglas et al., 2015)
	Metabolizable Energy (MJ/kg)	(Douglas et al., 2015)
	Lysine/Metabolizable Energy	(Douglas et al., 2015)
	Feed Form (Pellet, Crumble, Liquid, Expandate, Meal, Mash)	(Douglas et al., 2015; Silva et al., 2017)
	Different feeds according to sex (Yes/No)	(Silva et al., 2017)
	Number of Diets (1 to 7)	(Douglas et al., 2015; Silva et al., 2017)
Ambient/Living Conditions *(continuous measurement)*	Indoor Temperature (Average, Max, Min / Air, Floor)	(Banhazi & Black, 2009; Douglas et al., 2015; Van Hertem et al., 2017; Van Hyfte et al., 2015)
	Temperature Outside (Average)	(Douglas et al., 2015; Van Hertem et al., 2017; Van Hyfte et al., 2015)
	Relative Humidity (Average, Max, Min)	(Banhazi & Black, 2009; Van Hertem et al., 2017; Van Hyfte et al., 2015)
	CO_2, NH_3 concentration	(Banhazi & Black, 2009; Van Hyfte et al., 2015)
	Dust concentration	(Banhazi & Black, 2009; Van Hyfte et al., 2015)
	Ammonia concentration	(Van Hyfte et al., 2015)
	Airborne pathogen levels	(Banhazi & Black, 2009)
	Floor and animal wetness	(Banhazi & Black, 2009)

Table 2 – Production Batch Variables (continued)

Animal Body Condition

Animal Body Condition is a key indicator of overall efficiency of production factors and animal welfare. On the other hand, general body conformation or body fat are good measures of animal health.

Dimension	Metrics	Authors
Animal Body Condition *(continuous measurement)*	Weight (Initial, Ongoing, Final)	(Van Hertem et al., 2017)
	Uniformity	(Van Hertem et al., 2017)
	Body composition – e.g. back fat	(Banhazi & Black, 2009)
	Body conformation	(Banhazi & Black, 2009)

Table 3 – Animal Body Condition

Social Variables

The farmer still plays the leading role in a livestock production farm. Recent studies based on enquiries to European farmers reported the variables seen as most relevant for improvement with PLF systems (Lokhorst et al., 2012). This also suggests that these social farmer characteristics impact production the most, so we selected the five most valued.

Dimension	Metrics	Authors
Social Variables *(Periodic Evaluation)*	Labour conditions (physical, dust, environment, light…)	(Lokhorst et al., 2012)
	Number of labour hours	(Lokhorst et al., 2012)
	Pride/motivation to talk about and show animal and production facilities	(Lokhorst et al., 2012)
	Availability of advisory systems	(Lokhorst et al., 2012)
	Farm business successor to continue the farm	(Lokhorst et al., 2012)

Table 4 – Social Variables

Animal Behaviour

One of the methods used in PLF involve measuring responses continuously and directly on the animal rather than from the environment surrounding the animal (T. Norton & Berckmans, 2017). Behavioural changes that precede or accompany subclinical and clinical signs may have diagnostic value. Often referred to as sickness behaviour, this encompasses changes in feeding, drinking, and elimination behaviours, social behaviours, and locomotion and posture (Matthews et al., 2016). Automated early-warning systems with sensors to detect behavioural changes are key, especially because manual records by farm staff can be time consuming, subjective, and impractical, particularly on large-scale farms (Matthews et al., 2016).

Dimension	Metrics	Authors
Animal Behaviour *(continuous measurement)*	Activity Index	(Banhazi & Black, 2009; Matthews et al., 2016; Van Hertem et al., 2017)
	% of total time active	(Van Hertem et al., 2017)
	% of total time rested	(Van Hertem et al., 2017)
	Distribution Index	(Matthews et al., 2016; Van Hertem et al., 2017; Van Hyfte et al., 2015)
	Clustering	(Matthews et al., 2016)
	Coughs	(Matthews et al., 2016; Van Hertem et al., 2017; Van Hyfte et al., 2015)
	Vocalisation	(Matthews et al., 2016)
	Aggression	(Banhazi & Black, 2009; Matthews et al., 2016)
	Gait	(Matthews et al., 2016)
	Oestrus (heat) detection	(Banhazi & Black, 2009)
	Duration of Feeding	(Maselyne et al., 2013)
	Average inter-meal interval	(Maselyne et al., 2013)
	Frequency of visits to feeding area	(Stygar et al., 2018)
	Drinking Patterns	(Stygar et al., 2018)

Table 5 – Animal Behaviour Variables

Farm Installations Characteristics

These large and varied number of variables intend to characterize the farms themselves with the intention of later seeking correlation between farm features and productivity or sustainability goals (Agostini et al., 2015; Silva et al., 2017).

Dimension	Metrics	Authors
Installations *(Periodic Evaluation)*	Type of Production (Grower, Finisher, Grower and Finisher)	(Douglas et al., 2015)
	Infectious environment (Yes/No)	(Douglas et al., 2015)
	Labour force (Family, Non-Family)	(Silva et al., 2017)
	Number of barns (One; two or more)	(Silva et al., 2017)
	Stall age (<5 years, >5 years)	(Silva et al., 2017)
	Number of animals placed (<500, >500)	(Silva et al., 2017)
	Materials used to build the barn (Masonry, Wood, Mixed)	(Silva et al., 2017)
	Roof material (Clay; Asbestos; Zinc)	(Silva et al., 2017)
	Barn position relative to the sun (Diagonal; Contrary; Parallel)	(Silva et al., 2017)
	Trees around the facilities (Yes/No)	(Silva et al., 2017)
	Floor space (m^2)	(Douglas et al., 2015)
	Floor type (Solid, Fully slatted, Partially slatted)	(Douglas et al., 2015)
	Building type (Mechanically ventilated, Naturally ventilated, Automatic control of natural ventilation, Climate resp. chamber)	(Douglas et al., 2015; Silva et al., 2017)
	Humidifiers/nebulizers (Yes/No)	(Silva et al., 2017)
	Pigs per feeder	(Douglas et al., 2015)
	Feed Allowance (Ad libitum, Restricted)	(Douglas et al., 2015)
	Feeder model (Conical automatic, others)	(Silva et al., 2017)
	Feeder space (cm^2)	(Douglas et al., 2015)
	Drinker model (Nipple, Water cup, at Feeder)	(Douglas et al., 2015; Silva et al., 2017)
	Drinker space (cm^2)	(Douglas et al., 2015)

Table 6 – Farm Installations Characteristics

Farm Installations Characteristics Variables (continued)

Dimension	Metrics	Authors
Installations *(Periodic Evaluation)*	Treated Water (Yes/No)	(Silva et al., 2017)
	Bedding (Yes/No)	(Douglas et al., 2015)
	Number of animals per pen (<20, >20)	(Douglas et al., 2015; Silva et al., 2017; Stygar et al., 2018)
	K ($m^2/BW^{0.667}$) - floor space allowance p/unit of metabolic BW	(Douglas et al., 2015)
	Lighting regime (h/day)	(Douglas et al., 2015)
	Pens with shallow pools (Yes/No)	(Silva et al., 2017)

Table 7 – Farm Installations Characteristics (continued)

Post-Farm Measurements

Refers to data collected after animals leave farms and concerns transportation issues and meat quality evaluation at the slaughterhouse. Carcasses are examined by meat inspectors and remarks are made with respect to different diseases (e.g. Pneumonia accounts for 15.4% of remarks), injuries, and other abnormalities. This is a valuable data resource for disease prevention and enhancing animal welfare (Mathur, Vogelzang, Mulder, & Knol, 2018).

Dimension	Metrics	Authors
Transportation *(End Data)*	Transportation Environmental Conditions Log	(Banhazi & Black, 2009)
	Mortality rate during transport	(Van Hyfte et al., 2015)
	Number of injuries during transport	(Van Hyfte et al., 2015)
Meat Quality *(End Data)*	Meat quality in slaughterhouse	(Guarino et al., 2017)
	Number of animals rejected by slaughterhouse	(Van Hyfte et al., 2015)
	Uniformity (less slaughter waste and lean productions)	(Lokhorst et al., 2012; Van Hyfte et al., 2015)

Table 8 - Post-Farm Measurements

Production Efficiency/Environment Impact Dependent Variables

Here are the main efficiency KPIs:

- *Feed Efficiency* – One of the major factors that define overall efficiency of intensive livestock production systems that usually accounts for 60-70% of total costs (Douglas et al., 2015; Hartung et al., 2017). It is proven that feed cost can be reduced by 11% if individual feed consumption ratios are monitored and individual feed adjustments are made (Chastant-Maillard & Saint-Dizier, 2016);
- *Average Daily Weight Gain* – Animal weight is expected to increase in a predicted way, usually following references set by the genetic breeding potential of the animals (Guarino et al., 2017).
- *Mortality Rate* – A major KPI that indicates health status of livestock production batches;
- *Production Level* – In animal breeding farms, it is essential to control herd productivity (e.g. animals produced / parent animal or milk produced / cow) as a key competitive indicator instead of feed efficiency, for example (Chastant-Maillard & Saint-Dizier, 2016);
- *Environmental Impact* – Measures of Environment Impact of livestock production in farms that are very much relevant these days for sustainability evaluation (Animal Task Force, 2017).

These are also examples of dependent variables used for data exploration in livestock production.

Dimension	Metrics	Authors
Production Efficiency *(KPIs)*	Feed Conversion ratio (consumed feed/kg growth)	(Banhazi & Black, 2009; Douglas et al., 2015; Eastwood et al., 2013; Guarino et al., 2017; Lokhorst et al., 2012; Van Hyfte et al., 2015)
	Average Daily Weight Gain (g/day)	(Banhazi & Black, 2009; Douglas et al., 2015; Guarino et al., 2017; Lokhorst et al., 2012; Stygar et al., 2018; Van Hertem et al., 2017)
	Mortality Rate (%)	(Guarino et al., 2017; Lokhorst et al., 2012; Van Hertem et al., 2017; Van Hyfte et al., 2015)
	Production Level Rate (e.g. Piglets Weaned, Prod.Milk)	(Guarino et al., 2017)
Environment *(KPIs)*	Energy Efficiency	(Guarino et al., 2017)
	Water Efficiency	(Van Hertem et al., 2017; Van Hyfte et al., 2015)
	Environmental Impact	(Guarino et al., 2017; Lokhorst et al., 2012)
	GHG emissions (CO_2, NH_3)	(Van Hyfte et al., 2015)
	Unused nitrogen	(Van Hyfte et al., 2015)

Table 9 – Production Efficiency/Environment Impact Dependent Variables

Graphical Representation of Production Variables

The following figure represents and connects the identified variables with Sustainable Livestock Production Objectives and Precision Livestock Goals:

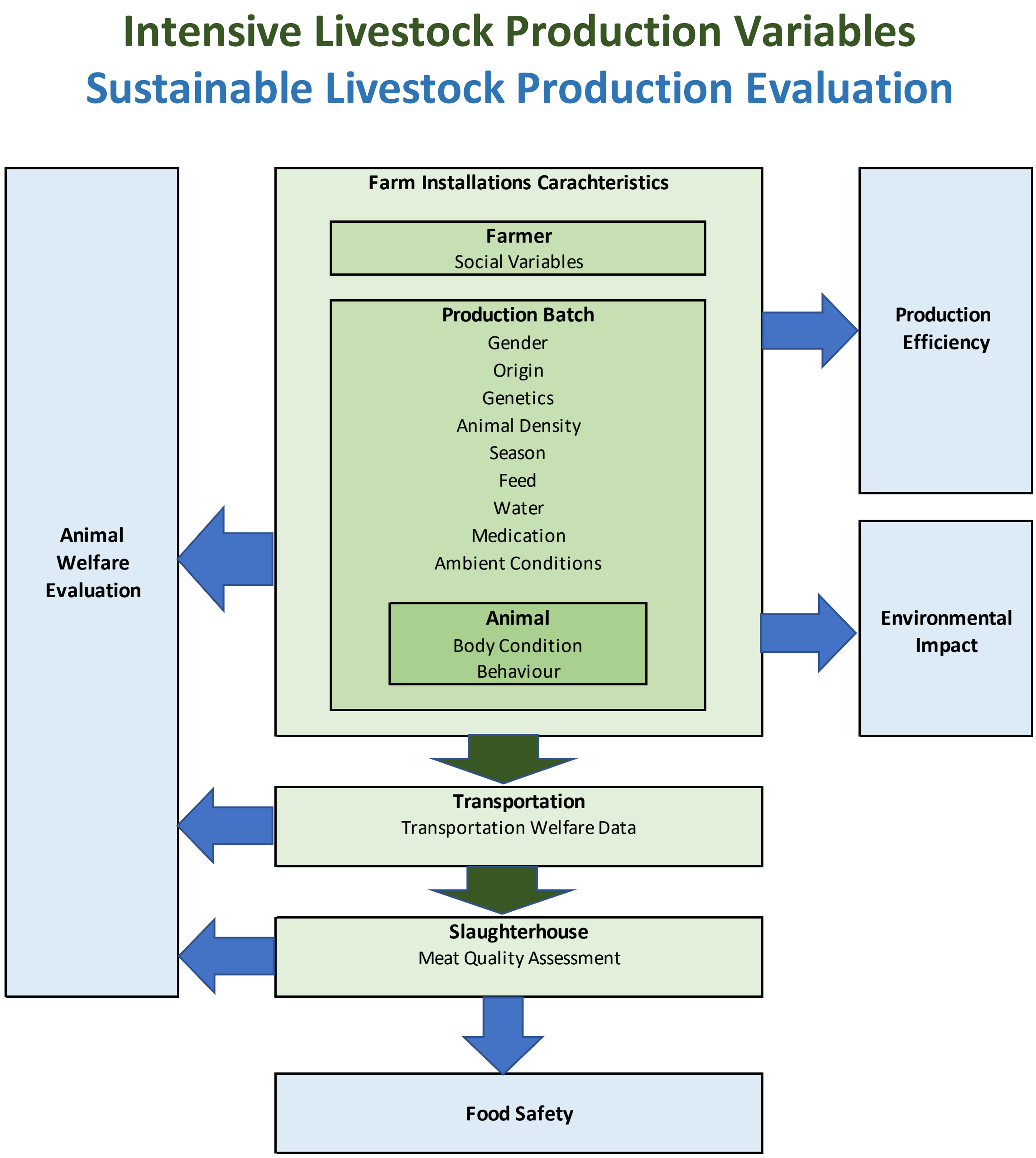
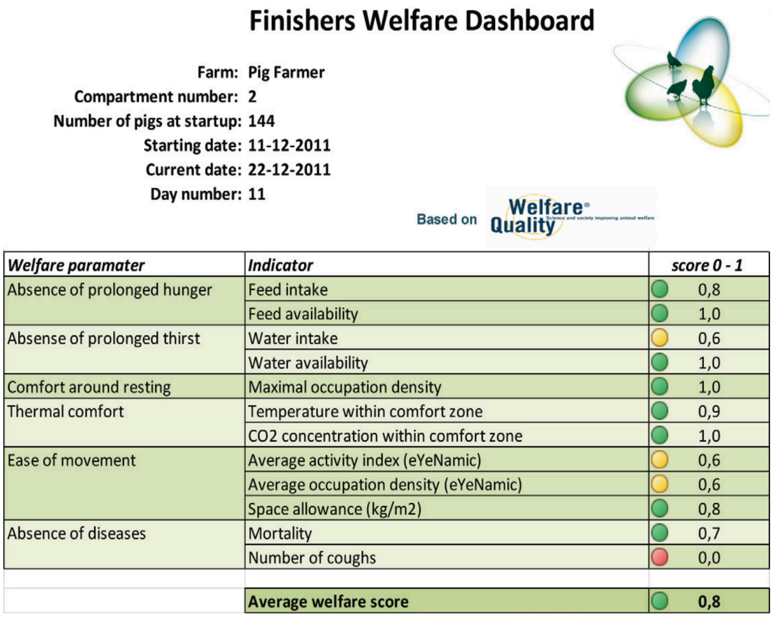


Figure 11 – Author's Graphical Representation of Livestock Production Variables

Examples of outputs of PLF systems representing different Variables dimensions:

The following figure represents an animal welfare dashboard based on some of the variables previously identified (Feed, Water, Density, Ambient Conditions, Behaviour and Mortality KPI):


Finishers Welfare Dashboard

Farm: Pig Farmer
Compartment number: 2
Number of pigs at startup: 144
Starting date: 11-12-2011
Current date: 22-12-2011
Day number: 11

Based on Welfare Quality

Welfare paramater	*Indicator*	*score 0 - 1*
Absence of prolonged hunger	Feed intake	0,8
	Feed availability	1,0
Absense of prolonged thirst	Water intake	0,6
	Water availability	1,0
Comfort around resting	Maximal occupation density	1,0
Thermal comfort	Temperature within comfort zone	0,9
	CO2 concentration within comfort zone	1,0
Ease of movement	Average activity index (eYeNamic)	0,6
	Average occupation density (eYeNamic)	0,6
	Space allowance (kg/m2)	0,8
Absence of diseases	Mortality	0,7
	Number of coughs	0,0
	Average welfare score	**0,8**

Figure 12 – Sample PLF-system output (Vranken & Berckmans, 2017)

Another example is a web-based farm production batch dashboard "Farm Status" where some of the variable dimensions identified are evaluated continuously (Feed, Water, Body Condition, Behaviour, Ambient Conditions):

Start Date	Expected End Date	Actual Date	Day count	Number of Animals
03/04/2015	13/05/2015	04/05/2015	31	28000

House	Feed	Water	Weight	Activity	Distribution	Environment
1						
2						

Figure 13 – Sample PLF-system output (Exadaktylos & Berckmans, 2016)

2.8. DESCRIPTIVE & PREDICTIVE PLF MODELS

Descriptive Models

Models can be created after data collection as tools for the interpretation of the factors related to the evaluated parameters, aiding in the identification of critical aspects of production (Pierozan et al., 2016). Three recent studies were selected as an example. These studies investigated the pig meat production sector in Brazil and Spain. Their goal was to understand what were the main variables that explained the variance of key feed efficiency and mortality ratios in fattening pig facilities:

Country	Dependent Variables	Determined by	Authors
Brazil	Feed Conversion Ratio, Daily Average Feed Consumption	Number of animals per pen, Feeder model, combination of origin-gender, initial and final body weights	(Pierozan et al., 2016; Silva et al., 2017)
Spain	Feed Conversion Ratio	Season, Genetic Breed (Pietrain Male), Gender segregation in pens, Unique Origin, Stall Age <10 years, lower initial body weight	(Agostini et al., 2015)
Spain	Mortality Rate	Season, Unique Origin, Water origin from well or public supply, Small Farms (<800 animals), higher initial body weight	(Agostini et al., 2015)

Table 10 – Examples of Descriptive Models

Real-time predictive algorithms

It is better to detect a problem while the animal is in production instead of finding the problem later on at the slaughterhouse. PLF can provide real-time warnings when something goes wrong so that immediate action can be taken by the farmer (D. Berckmans, 2013). One of the breakthrough PLF systems applications is real-time predictive algorithms that can analyse individual animal features or behaviour and predict an undesired future condition. This is challenging, because an animal is a CITD system that stands for complex, individually different, time-varying, and dynamic (T. Norton & Berckmans, 2017).

In this PLF application example, the goal is to automatically evaluate the lameness status of a dairy cow by analysing image data from a depth camera. Lameness seems to be the number one animal welfare problem in milk cows so a robust algorithm for lameness detection is very important for dairy farmers (T. Norton & Berckmans, 2017):

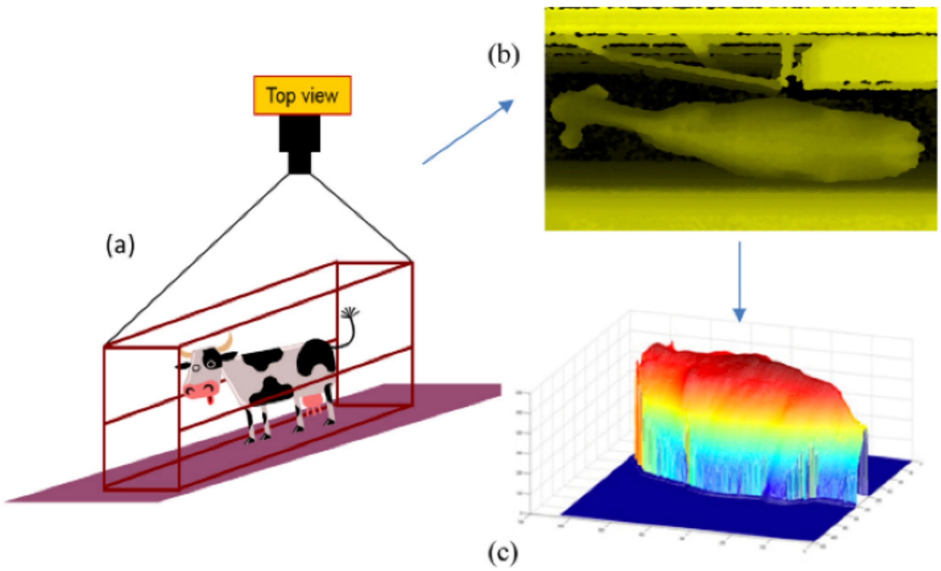


Figure 14 – Depth Camera collecting bio-signal cow data (T. Norton & Berckmans, 2017)

The process is achieved by developing a computer algorithm that analyses the variables of the image (the field data or bio-signal) and selecting the feature variable that best determines the gait of the animal that by hypothesis will express the lameness status (the target variable). The process is very time-intensive as researchers must do *labelling* – manually analyse the image of each individual animal and mark their gait to create a baseline for that animal and then detect significant deviations in future images and predict a lameness status (T. Norton & Berckmans, 2017).

A "gold standard" is essential to these researches. This gold standard or reference point can be defined as a state-of-the-art scientific measurement or method that enables us to draw a conclusion relating to the final algorithm objective or target variable status, in this case, the degree of lameness of a cow (T. Norton & Berckmans, 2017). An accurate gold standard is usually the most difficult to establish in PLF algorithms: We cannot proceed with the target variable if this gold standard cannot be determined (T. Norton & Berckmans, 2017).

The development of successful applications requires multi-disciplinary technological and veterinary teams and the application of a good method (T. Norton & Berckmans, 2017). As scholars in different disciplines often work isolated, recent findings suggest that most results and findings of the PLF technology are unknown to animal scientists, veterinarians, ethologists, while most PLF experts have poor understanding of the needs of the other groups (Exadaktylos & Berckmans, 2016).

3. PROJECT METHODOLOGY

3.1. Project Management – SCRUM

Farmcontrol uses the mainstream software development process SCRUM, an agile methodology that was developed in the early 90's as a framework for managing complex development projects (Schwaber, 2004). It focuses on monitoring software development cycles from Requirement Specifications to Integration Tests and provides support for the intermediary Design, Coding and Unit Testing Phases (Gouveia, 2015).

Team Structure

- *ScrumMaster* – It can be compared to a typical Project Manager although with different activities and responsibilities. In Scrum, teams are usually self-managed. The ScrumMaster is considered a facilitator (as opposed to a Project Manager) as he only has to ensure that Scrum rules and practices are followed. The ScrumMaster is, of course, responsible for project success and must help the Product Owner select the most valuable Product Backlog priorities and help the development team turn the Product Backlog into functionality (Gouveia, 2015; Schwaber, 2004). In Farmcontrol, is the ScrumMaster is the CTO, who regularly assesses project resources, timeline, budget and quality.
- *Product Owner* – Its main responsibility is to decide which features and functionality to build and dictate product backlog priorities. It must be close to the Development Team at all times and ensure the proper understanding of specifications (Gouveia, 2015; Schwaber, 2004). In Farmcontrol, the Product Owner is the CEO.
- *Development Team* – executes software coding for delivering the required functionalities. It is self-managed and requires face-to-face communication and teamwork with the goal of achieving synergy efficiency (Gouveia, 2015; Schwaber, 2004). In Farmcontrol, the development team is formed by Farmcontrol's software developers or sub-contracted developers, and they are both on a common scrum framework.

Scrum Process Practices

- *Sprint* – a timed 30-calendar day event (Farmcontrol also uses 15), where the Development Team produces a Potentially Shippable Product Increment by completing the tasks required to obtain the functionalities included in the Sprint Backlog. Thus, the outcome is ready to implement and present to project stakeholders and complete in terms of development, testing and documentation (Gouveia, 2015; Schwaber, 2004). In Farmcontrol, user experience testing, software bug testing and software versioning update are made at each sprint;
- *Sprint Planning Meeting* – It is usually divided into two 4-hour parts. On the first part, the Product Owner presents backlog priority requirements and decides what can be turned into functionality in the next Sprint with the highest business return. During the second part, the Development Team plans the necessary work to be done on the next Sprint (Gouveia, 2015; Schwaber, 2004).

- *Daily Scrum* – Usually a 15-minute meeting, early in the day, with the whole Development Team in order to obtain work synchronization between them (Gouveia, 2015; Schwaber, 2004).
- *Sprint Review Meeting* – Usually a 4-hour meeting where the Development Team presents the work that was done to the Product Owner and possibly to some project Stakeholders. Once the presentations are over, stakeholders must give their impressions and discuss any desired changes, prioritizing them. A potential rearrangement of the Product Backlog is discussed at the end of the meeting (Gouveia, 2015; Schwaber, 2004).
- *Sprint Retrospective Meeting* – An opportunity to inspect and adapt the sprint process by basically reviewing what went well and what must be improved for the next sprint (Gouveia, 2015; Schwaber, 2004).

Scrum Artefacts

- *Product Backlog* – a list of prioritized requirements made by the Product Owner and project stakeholders that assures an effective and efficient communication between the Product Owner and the Development Team (Gouveia, 2015);
- *Sprint Backlog* – Usually a Product Backlog represents many months of work so multiple sprints are required. The Sprint Backlog is built as specifications are added by the product owner and scrum master. The Development Team is responsible for determining which items they can realistically turn into functionality by working at a sustainable pace (Gouveia, 2015).

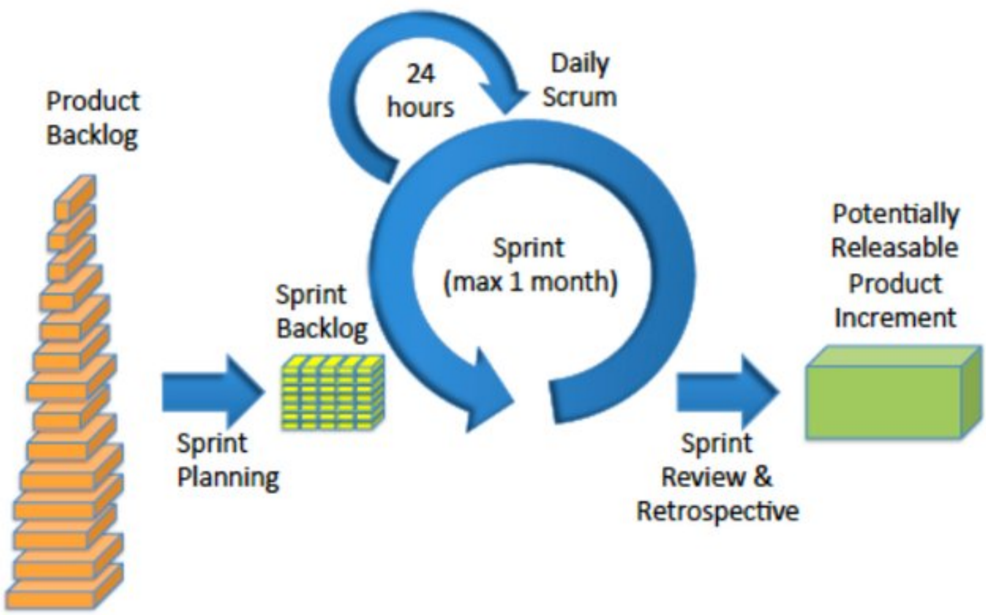


Figure 15 – Scrum Process Diagram (Freudenberg, 2013)

3.2. SOFTWARE DEVELOPMENT PROCESS

3.2.1. Requirement Analysis

At this stage, the Farmcontrol team defines a series of documentation to clearly define what the software should do to solve a particular business problem and which information to present. In this project work the basis for documentation was done by internal team validation, client/end user counselling and literature review.

Figure 16 – Requirement Analysis Workflow

3.2.2. Software Design

The Dev team usually decides the best technical approach to design the software by deciding on database design, information flow charts, use of case specification and functionalities diagrams. Constraints are usually defined by previous software versions and current software infrastructure. Usually there are also some initial “mock-up” screens for the team and client to validate user interface choices.

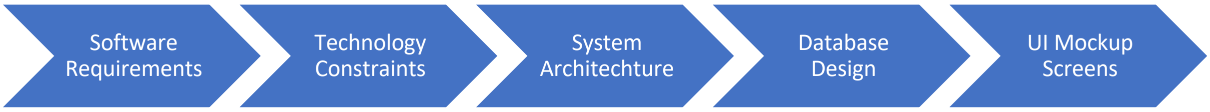


Figure 17 – Software Design Workflow

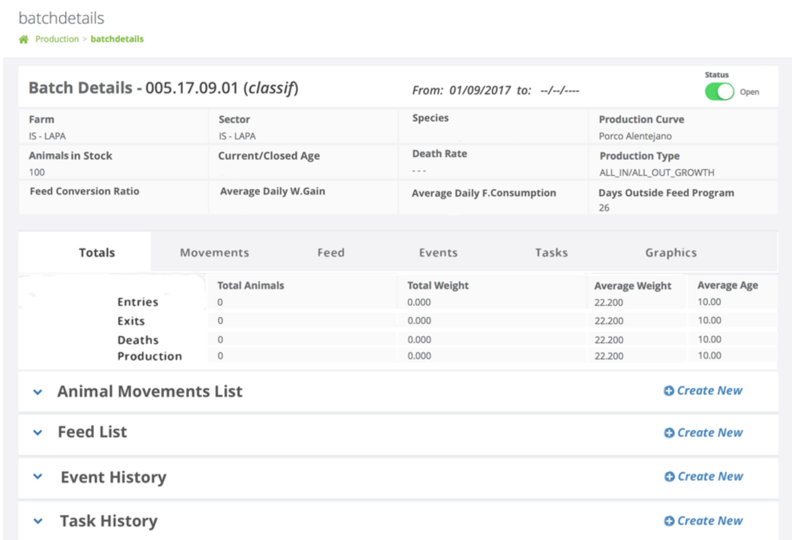


Figure 18 – Sample Mockup Screen

3.2.3. Software Development

Each sprint is managed by a sprint report excel file where individual GitLab-made issues were created and selected for implementation on each sprint.

The following is a sample of the sprint report produced at each stage:

Farmcontrol	Sprint	SPRINT 1

FROM	TO	DURATION
20/08/19	08/09/19	20 day(s)

PRODUCT OWNER	SCRUM MASTER
PRODUCT OWNER	SCRUM MASTER

FEATURE GROUPS				
ID	DESCRIPTION	DEV HRS	TEST HRS	TOT.COST
		0	0	- €
		0	0	- €
		0	0	- €
		0	0	- €
		0	0	- €
		0	0	- €
		0	0	- €
OTHERS		48	---	9.600,00 €
TOTAL		48	0	9.600,00 €

DEVELOPERS/DAYS					
[JARAUJO]	[MANEL]	[JOAQUIM]	[CARLOS]	[LUIS]	[RUBEN]
14	14	14	14	14	14

TESTERS/DAYS					
[TESTER1]	[TESTER2]	[TESTER3]	[TESTER4]	[TESTER5]	[TESTER6]
2	2	2			

TIME ALLOWANCE					
AVAILABLE	DEVELOP	TESTING	MEETINGS	OTHER	FREE TIME
720	0	48	48	4	620

DEVELOP TIME DETAIL					
PLANNED		COMPLETED		TESTING	
ITEMS	EFFORT	ITEMS	EFFORT	ITEMS	EFFORT
0	0	0	0	0	0

Notes

Farmcontrol Sprint: SPRINT 1

OPENING MEETING	
DATE	PRESENCES

CLOSING MEETING	
DATE	PRESENCES

Figure 19 – Sample Sprint Report

The implemented methodology proved to be efficient by continuously updating open sprint issues and testing them at the same time. The usual time structure was a 3-week period with the following standard template:

		Week 0	DEV SPRINT			Week 4
			Week 1	Week 2	Week 3	
Day 1	AM	SPECS	Opening Meeting	Developing Testing Start Documentation	Closing UAT Meeting	PROD DEPLOY
	PM		Developing		Debugging Testing Finalize Documentation Backlog Adding	
Day 2	AM					
	PM					
Day 3	AM					
	PM					
Day 4	AM					
	PM					
Day 5	AM					
	PM					

Figure 20 – Usual Dev Sprint Schedule

3.2.4. Gitlab - Management and Deployment Tool

Farmcontrol uses the Gitlab online tool (www.gitlab.com) for both Product Backlog and Sprint Backlog management. This tool is also used for software deployment and versioning. Gitlab is a solution for native cloud development through process centralization in a single application. It is essentially a Git repository manager with Wiki and issue-tracking that integrates the Kubernetes system. This system enables automatic deployment, scaling and management of containerized applications. GitLab, in turn, enables direct integration with the Google Cloud Platform, which provides a Kubernetes Engine, as well as other complementary services.

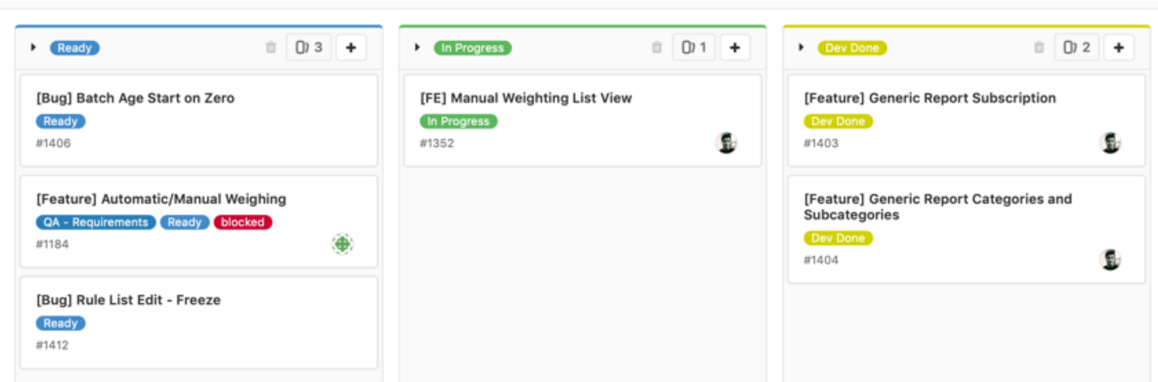


Figure 21 – Gitlab Dev Board Sample

Farmcontrol has 3 segmented instances for development:

- *Development* – Where programmers do raw coding and basic testing;
- *Staging* – Where pre-production tests are made;
- *Production* – Current Commercial Version.

Each time a developer pushes to a branch with an associated pipeline, this pipeline will be executed and will generate an image. It will then be recorded on its own Container Registry, and the image will be deployed. The following figure exemplifies a pipeline:

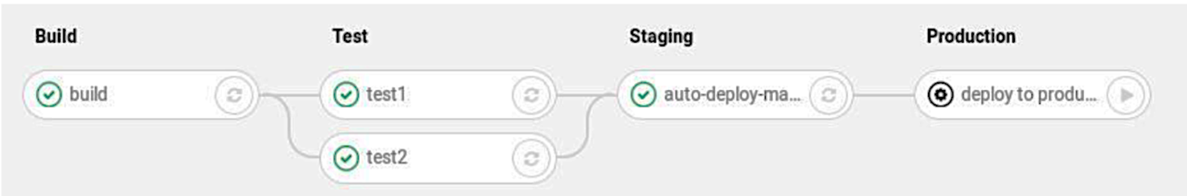


Figure 22 – Deploy Pipeline Example in Gitlab

3.2.5. Test Design

For every new feature, a test case is defined as a set of actions performed in a particular way to verify it. Usually a test case is drafted with a description of what feature is being tested, which inputs are needed and what output is expected, an explanation of how the test will be executed and setup context information necessary for the testing. A test case is usually described in no more than 15 steps. After the test is performed a proof is usually attached. The developer team uses the Gitlab online tool to coordinate work, signalling every phase of testing and bug fixing of the following workflow:

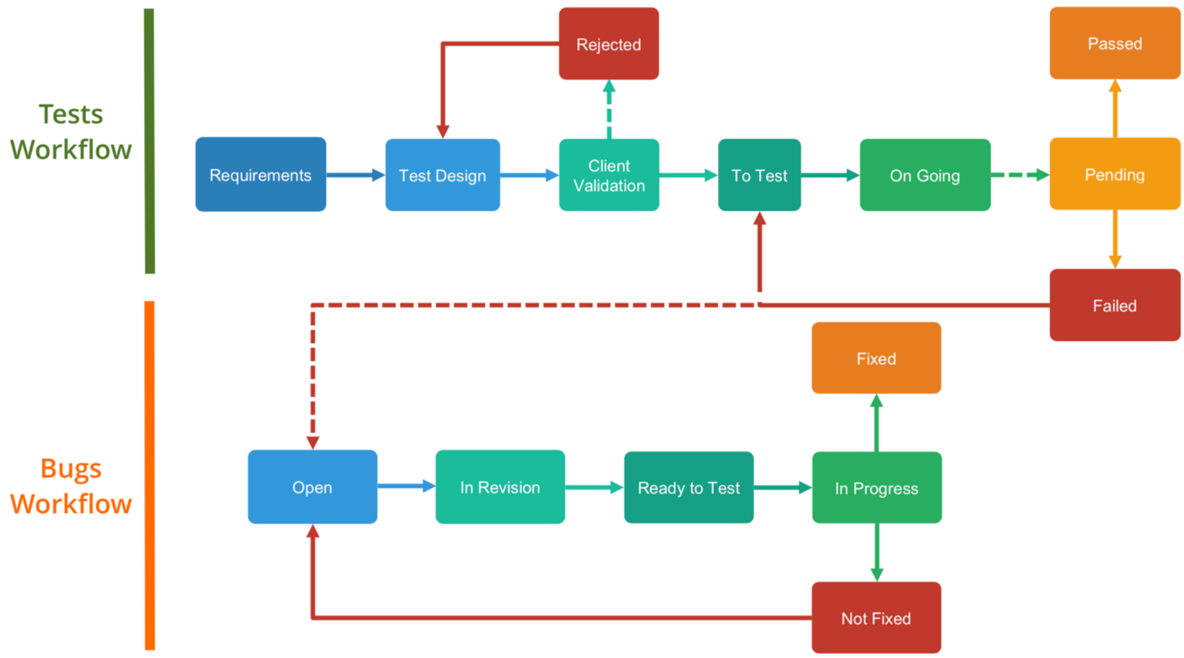


Figure 23 – Test Cases and Bugs Workflow

Test Workflow:

<u>Requirements</u> – New Features on the developer side

<u>Test Design</u> – Test Cases Design for the new features

<u>Client Validation</u> – At the option of Farmcontrol, Client Test Cases Validation or User Acceptance Tests (UAT) are performed very close to the developer team sprint in order to quickly identify new bugs or badly written/insufficient specifications. If this is performed too late, there is a greater probability of increased developing costs for solving these kinds of problems.

<u>Rejected</u> – Rejected Test Cases for test reformulation

<u>To Test</u> – Accepted Test Cases

<u>On Going</u> – Test Cases Being Tested

<u>Pending</u> – Blocked Test Cases due to a specific issue or doubt

<u>Passed/Failed</u> – Passed or Failed Test Cases

Bug Fixing Workflow:

<u>Open</u> – Bugs found on the developer side

<u>In Revision</u> – Bugs that are being fixed

<u>Ready to Test/In Progress</u> – Bugs ready to be tested/Bugs that are being tested

<u>Fixed/Not Fixed Bugs</u>

Tests were designed and recorded in the Gitlab software such as the following sample:

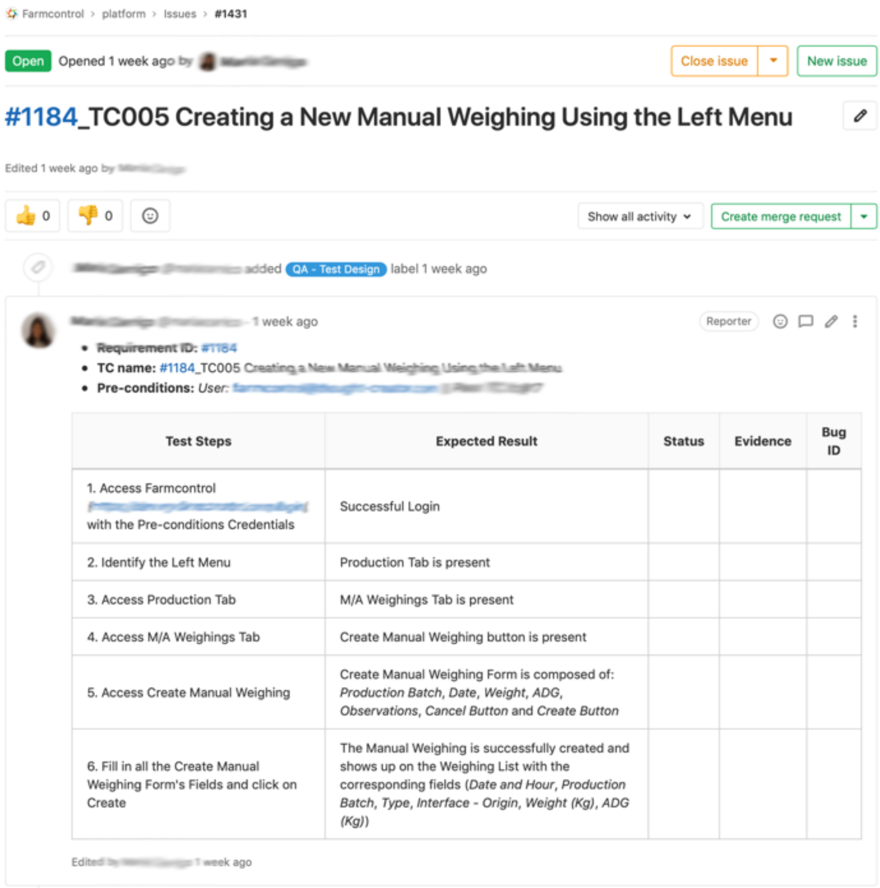


Figure 24 – Sample Test Design

System Integration Tests

As the new production module is integrated into an already functional software, integration tests are necessary to verify that the new features maintain the integrity and functionality of other subsystems. Older tests for other features are usually re-run in critical applications.

3.2.6. Software Documentation

QA Testers were in charge of updating the Product Manual in Microsoft Word files.

4. PROJECT CONCEPTION

4.1. TECHNICAL ASSUMPTIONS AND CONSTRAINTS

This project is required to be integrated with Farmcontrol's cloud software that was already deployed so the development team must comply with current technologies used, infrastructure and software design constraints.

4.1.1. Technologies & System Components

State-of-the-art technologies were chosen for the development of the Farmcontrol solution to allow efforts to be directed to functionality and drastically reduce time for setting up and preparing the frameworks:

Spring boot – lets you create production-ready Java applications without worrying about configuration, thanks to the automatic configuration mechanisms offered. Consists of the Spring Framework and a set of third-party libraries.

RabbitMQ – an easy-to-deploy Spring Boot-compliant open source message broker that is ready for high availability requirements.

PostgreSQL – an open source relational database engine that uses and extends the SQL language and is stored safely and ready to scale and process complex workloads.

GIT – Source code versioning system of the solution, implemented GitFlow – branching model for GIT that allows coordination of the work between the different development actors.

Currently, the Farmcontrol system consists of the following components:

Web-App – System UI;

System-Core – Implementation of all business logic;

RabbitMQ – Message Broker;

Middleware – EndPoint where farm IoT gateways connect.

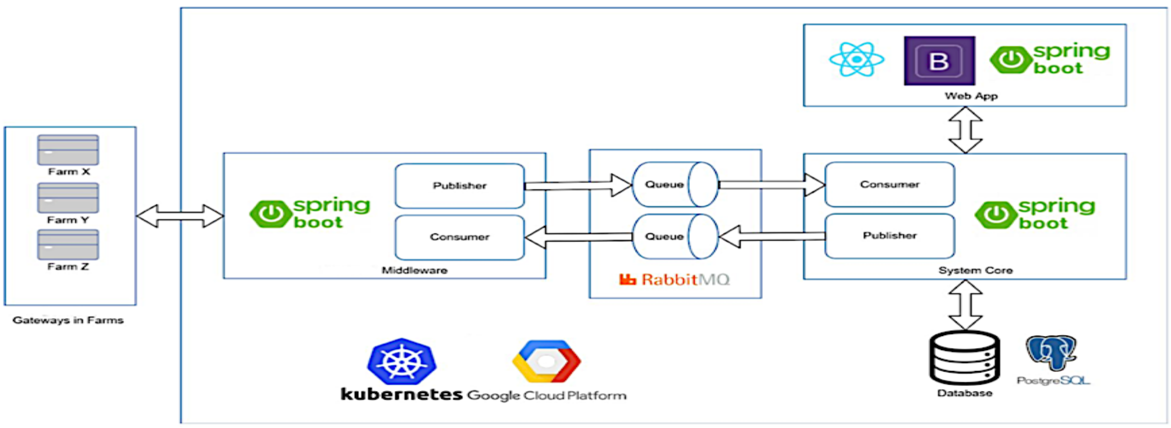


Figure 25 – Technology and System Components

4.1.2. Multi-tenant Support

Platform architecture is designed to share one instance with different tenants. Every tenant has a dedicated share of the instance with data segregation, user management and configurations. Each application instance is created by an authorized user at Root level that can monitor and act in every instance. An “entity” is a concept that already exists on the software and can be considered a Partner, Group, an enterprise, a Farm or a Sector (of the farm).

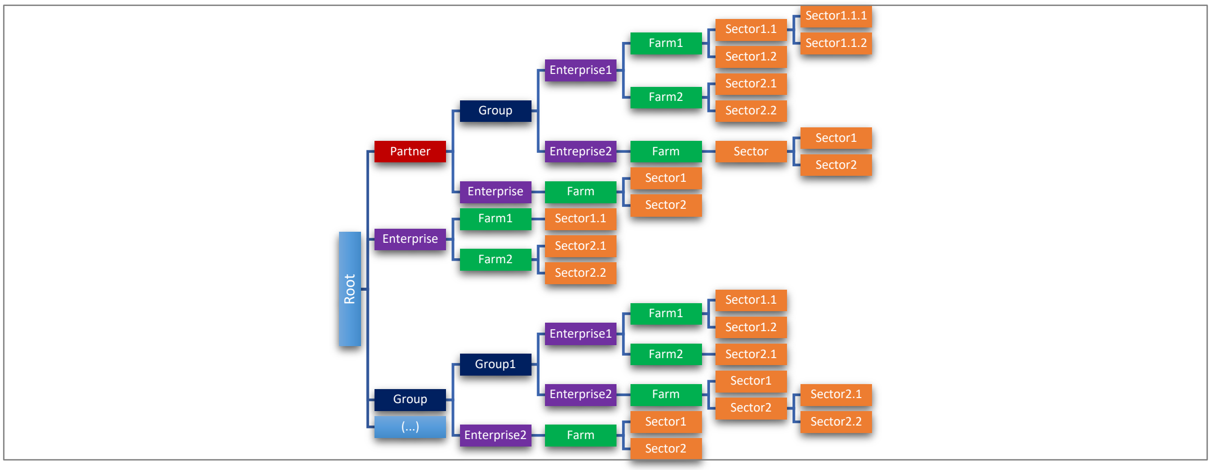


Figure 26 – Example of a multi-tenant instance hierarchy

The Platform shall consider the following entities and its correspondent characteristics and hierarchy rules:

Entity	Entity Type	Has Users	Characteristics
Root	Root	✓	• Platform owner • Monitors overall platform and instances
Group	Tenant	✓	• Legal entity that represents a group of enterprises • May have sub-groups
Enterprise	Tenant	✓	• Legal entity that uses the platform to manage production • Has farms
Farm	Physical	x	• Only Enterprise as a parent • Links a Tenant entity with the real world • May have associated devices (gateways, collectors, sensors, actuators)
Sector	Physical	x	• Only Farm as a parent • Represents an area within a farm • Can have a sub-sector • Has associated devices (sensors and actuators)

Table 11 – Entities characteristics and hierarchy rules in Farmcontrol

4.1.3. User Management

User Role and Permissions

A user is created with a set of functionality permissions, combined within a role and a set of entities access that limit user access to specific entities on a user branch. The platform can create and manage roles and permissions. The Admin role, at Root level entity, has access to all platform data and functionalities. The functionality to manage users, roles and permissions can be delegated by the Admin user to a special user (typically a Super User) that is responsible for managing the platform at each eligible entity.

Single Sign-on & Aggregated View

With a single username and password, a Root user is able to access different instances. It is also able to access different entities within each instance. The user can have data aggregation depending on the hierarchy node the user is in and the ability to drill down to a more granular entity.

Audit Trail

The platform provides an audit trail functionality so that relevant user actions are record and can be visualized by authorized users. User Id, Date/time of access, Action Performed and Action Context (Description; New / Old Value; etc.) are examples of the information that is retained.

4.1.4. User Interface Design

General Colour/Font Schema

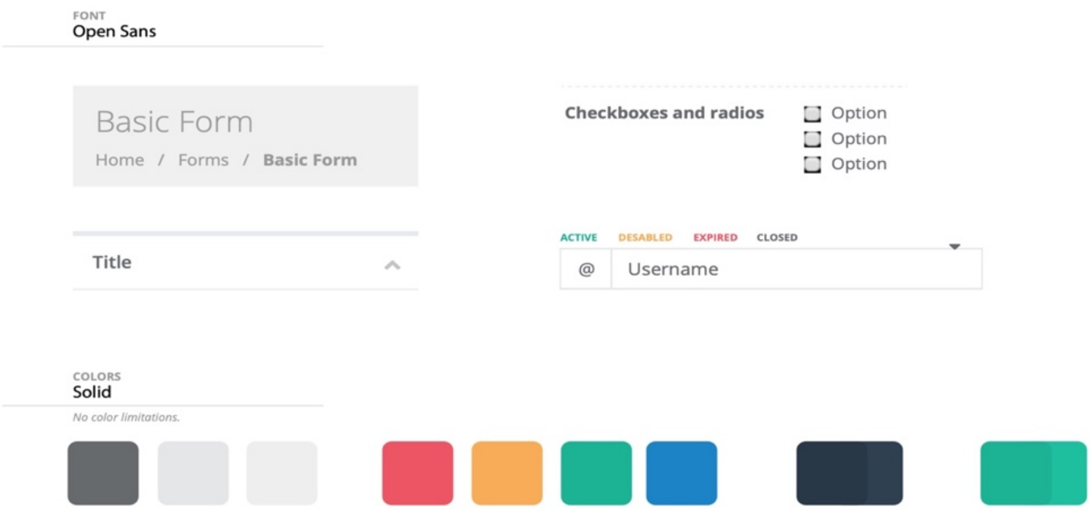


Figure 27 – Platform General Colour/Font Schema

General Platform Screen Elements

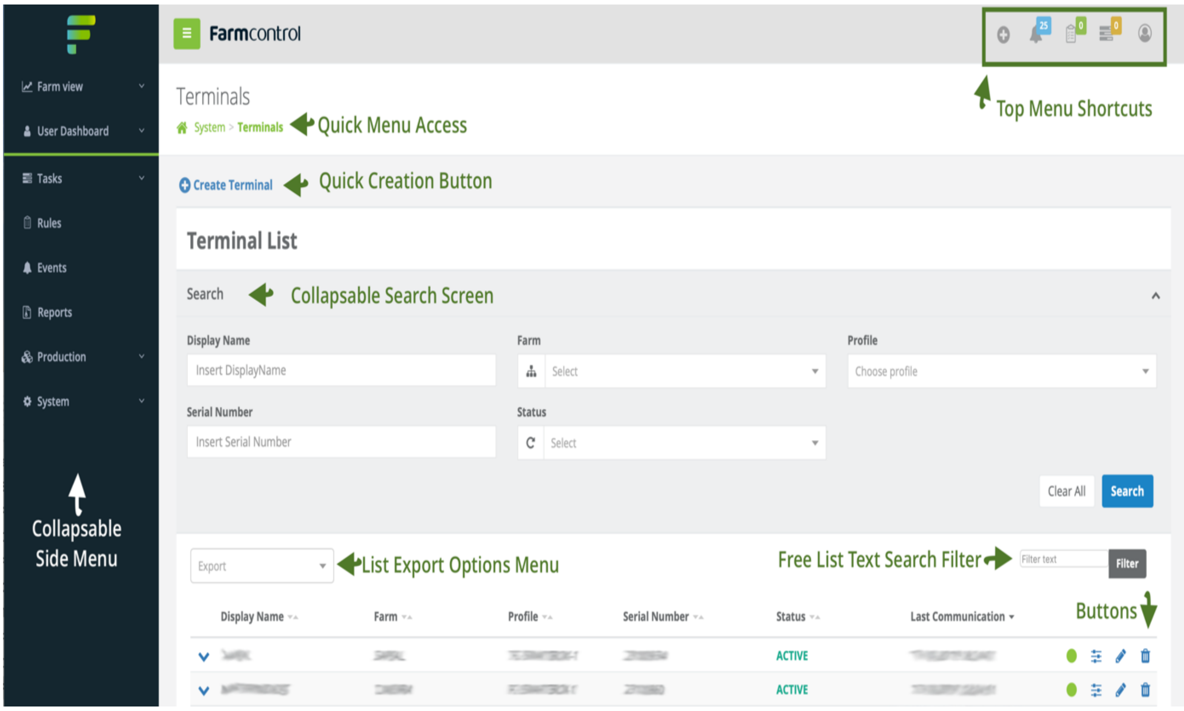


Figure 28 – General Platform Screen Elements

Dashboards

Users can access common IoT dashboards (known in the software as the “Farmview” feature). Here is a sample of the information presented:

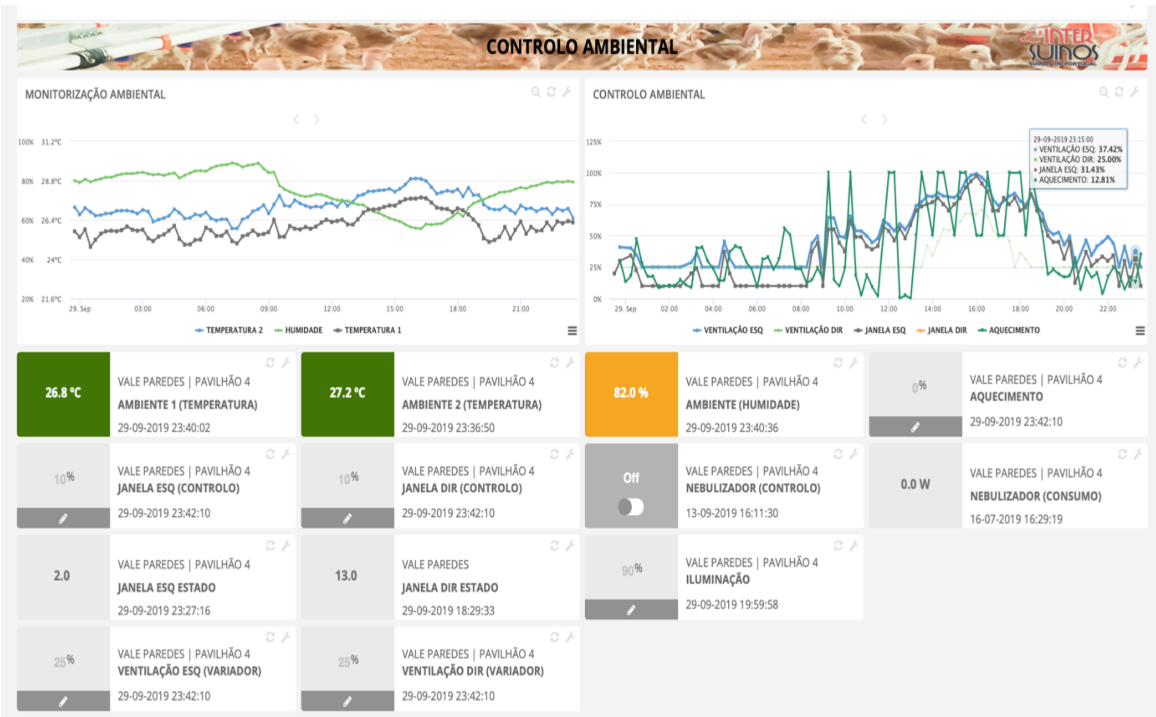


Figure 29 – Sample Farmview Dashboards

4.2. NON-FUNCTIONAL REQUIREMENTS

Reliability

- All data is available on a cloud solution and accessed through any online computer with a common web browser;
- The software should be stable and reliable to inspire trust on the user;
- Goal is set for a minimum of 1 month between failures at launch;
- Historical Data should have fast and easy access;

Performance

- Manual Records should take less than 1 second to save;
- Automated Events should take less than 2 seconds to process and notify;
- Data Widgets should take less than 5 seconds to process and display;
- Data Charts should take less than 20 seconds to process and display;
- E-mailed reports should take less than 1 minute to process and notify;
- Data queries and database design should be optimized for performance.

Usability

- The software is available in English, Portuguese and Spanish;
- The new software core functions should be easy to understand by the user;
- The User Interface should be enjoyable by the user and similar across the software;
- Search and Filter functions should be similar across the software;
- Cross-device support refers to desktop, tablet and mobile browsers such as Chrome (v52), Firefox (v46), Edge (v14), IE (v11) and Safari (v10).

Testability

- Support team should monitor system performance daily;
- Support team should do monthly data stress tests for evaluation;
- Usability Score should be based on periodic user tests;
- A test case and test plans should accompany the system and be regularly updated.

Documentation and Support

- A Software Manual should be created for the new functions;
- For bigger clients, on-premises teaching classes should be scheduled;
- A support contact should be available on business hours;
- A premium support package is offered – "Farmcare" Service.

Privacy and Security

- Privacy policies for users are defined and comply with current law obligations;
- Data is stored on Google Cloud Platform servers located in Europe;
- Production data is owned by the clients and can be used anonymously if authorized by the clients.

4.3. Functional Requirements

4.3.1. Business Requirements Overview

The livestock production sector has a broad business context. Farmcontrol focused on the most relevant production system which is all-in/all-out batch fattening of animals. In this production system a group of animals, usually of the same origin and age, are put on a farm barn where they are cared for until the designated programmed age of slaughter. The farmer's goal is to maximize meat production taking the least time and using the least feed and other resources, while complying with the law and good production practices of animal welfare, sensible resource usage and environment safety. Usually businesses must provide full traceability of production batches regarding written records of origin of animals, feed and medication.

Collection of Livestock Production Batch Records

The software must allow the collection of animal production batch information that was not given by automated sensors, in real-time and digital format, this way facilitating the rapid dissemination and use of more effective measures for reported problems.

Examples of data collected:

- Batch metadata such as dates of start/end, animal species and genetics;
- Animal Stock Records and mortality causes;
- Feed Movements;
- Manual Animal Weightings done by the farmer;
- Records of farmer tasks performed to the batch;
- Record of relevant manual events/alerts created by the farmer side-by-side with the current solution of events/alerts created by the installed sensors.

Benchmarking / Production Curves

Users should be able to create "Production Curves" that allow them to manage daily benchmarks in order to evaluate the compliance of the information collected by the Farmcontrol solution.

The Production Curve functionality aims at being a pre-set goal and benchmark tool to set global or daily production batch KPI goals. You can also set a trigger task for a specific day of the age of a batch.

Users can create and manage multiple production curves that allows them to cope with a variety of scenarios, such as multiple genetics, different production conditions or seasonality.

A production curve can have the following data:

- Global KPI goals for the production batch
- Daily Environmental Variables Thresholds (Maximum and Minimum Temp., CO_2, Humidity)
- Daily Weight Goal
- Daily Feed/Water Consumption
- Optional triggered tasks for each day of age

Farm Characterization

Users should be able to characterize each farm's features that can correlate to optimal results on animal production (construction, ventilation, feeding equipment, animal group organization, etc.).

Manual Events Management

Users should be able to use the current IoT automated event structure to create manual events in order to generate records of problems that exist on farms and that are not originated by sensor alarms. These events can also be used to incorporate relevant information from other sources (External Software, Lab Analysis, etc.).

Task/Knowledge Management

The new software module should provide a simple Task Manager that incorporates Task Templates in order to retain knowledge of the most important tasks by managing standard company procedures in a simple repository. Task Templates allow farmers to collect procedures for each standard task in a farm, on a day-to-day basis, enabling a more efficient quality control, and retain some knowledge that can easily be used by new employees or as a consultation tool for current employees. Task management also allows to enter medications and other farm inputs, avoiding the complexity of managing stocks, references, etc.

By applying the same collective intelligence concepts referred before, we think we can build a task manager with a Task Template repository where organizations can ask their employees to build common procedures that are made available for voting to the entire team. There would be incentives for the best contributions and usually a responsible person to coordinate and validate submitted ideas. This feature will allow effective Team Collaboration, but also help retain shareable knowledge on farms.

This "genome" would look like this:

WHAT?		WHO?	WHY?	HOW?
Create	Description of Critical Task Processes with custom checklists	Crowd	Love, Glory	Collaboration
Decide	Whether to Agree with the proposed task knowledge	Crowd	Love, Glory	Voting
Decide	Whether the Task Created is to be made available as valid usable knowledge and how it is classified	Technical Direction	Love, Money	Hierarchy
Decide	Whether the Tasks Available are to be incorporated on daily work as planned or triggered Task events	Crowd	Money	Hierarchy / Individual

Table 12 – The Collective Intelligence Genome for a Farmer's Organization

The process flow would look like this:

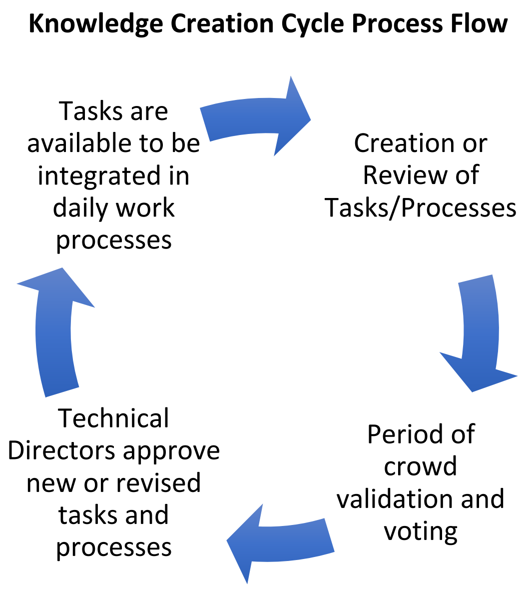


Figure 30 – Knowledge Creation Cycle in a Farmer's Organization (Author)

4.3.2. Software Outputs

Collected information is presented to the user in three ways:

Screen Lists

Screen view of data filtered data lists.

Exported Lists

Data listed in the software platform screen can be exported to Excel or CSV format – A functionality that is already available on the platform and integrated on the new module.

Livestock Batch Report

A printable PDF format file with all transaction traceability and production KPIs of production batch records associated with real-time data charts from sensors on farms.

Dashboard Widgets

Aggregation of live data from batches to be published on the software dashboard feature.

4.3.3. Search and List Feature

The search and list features are used on the framework of this software's generic UI options. There is also a text search option on top of each list. Below is a sample of a search/list feature specification:

Example:

Genetics Search and List

Search fields:

- Name – text
- Entity – multi-selection dropdown list (only Tenant Entity)
- Species – multi-selection dropdown list
- Status - multi-selection dropdown list

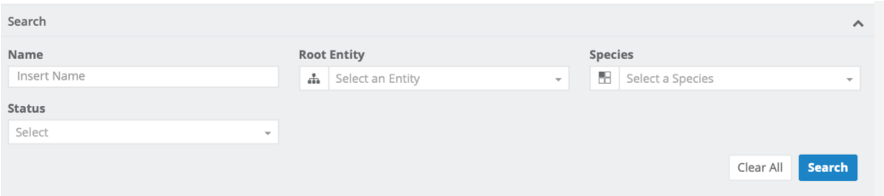


Figure 31 – Genetics List Search

List Columns:

- Name
- Entity (only Tenant Entity)
- Species
- Status

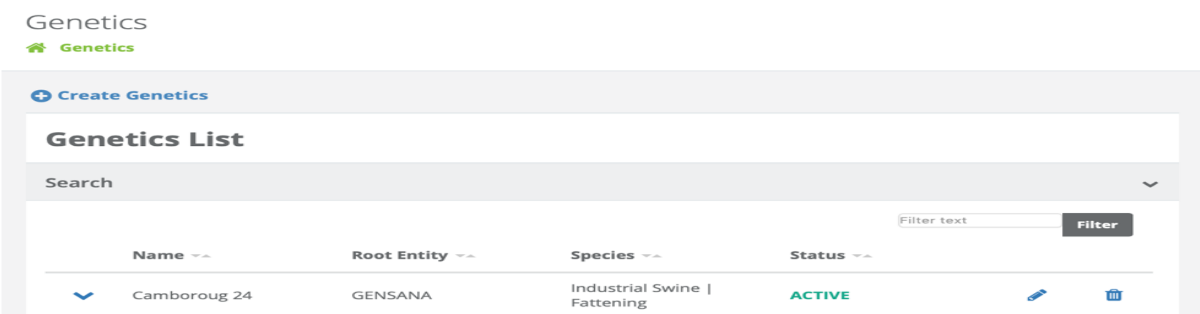


Figure 32 – Genetics List

4.3.4. Variables Selection

In preparation for the software specifications it was important to begin by selecting the main livestock variables to incorporate, evaluate where to collect those variables data (either from manual log records or IoT sensors) and which KPIs should be reported.

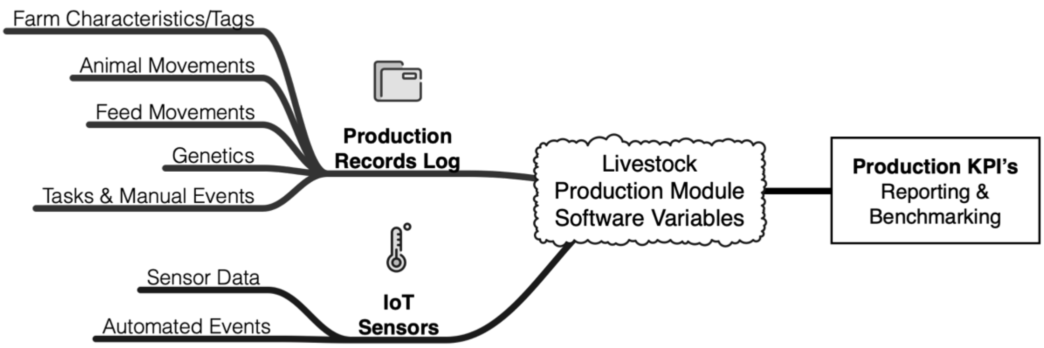


Figure 33 – Software Variables

Batch Production Records Log

These records depend on each production batch. They are mostly records that were input manually by farmers or central offices regarding all animal and feed inputs, medication records, animal genetic line, and animal density.

Dimension	Production Batch Details	Software Feature
Batch Management	Number/Weight of animal movements	Animal Movement Records (Entries, Exits, Mortality)
	Number of Origins of the Pigs	Animal Movement Records (Number of Different Entries)
	Weather Season (Determined by Dates)	Animal Movement Records (Dates of Entry/Exit)
	Gender (Male, Castrated Male, Female, Male and Female)	Animal Movement Records (Entry Observations)
Genetics	Genetic Breeds (created by the client)	Batch Records (Genetic)
Feed Program	Total Feed Weight consumed	Feed Movement Records (Feed Weight)
	Feed Factory Origin	Feed Movement Records (Factory and Delivery Docs)
	Feed Form (Pellet, Crumble, Liquid, Expandate, Meal, Mash)	Feed Movement Records (Feed Entry Observations)
	Number of Diets (1 to 7)	Feed Movement Records (Different types of Feed Entries)
Medication Protocol	Use of Antibiotics (Yes/No)	Task Medication Records
	Number of animals treated with medication	Task Medication Records
Installations	Floor space (m2)	Farm Sector Records
	Stocking density (numbers on animals/m2 in de the barn)	Calculated Batch KPI (Sq.Meters per Animal)

Table 13 – Types of Batch Production Records

Farm Characteristics

This feature required a different approach, due to its extensive usage and criteria. Farm feature evaluation is a very subjective issue among technicians. Some of them will require one or two main characteristics, while others will require a dozen or more. So, it was decided that the “tag” approach was the best way to approach this feature, as it provided an easy way to characterize a farm while maintaining software simplicity and usage openness. Some sample tags will be created for user guidance, but the user can create its own personalized tags:

Farm Charachteristics	Created Tags	Default Tag for Data Mining
Type of Production (Grower, Finisher, Grower and Finisher)	Grower, Finisher	Grower/Finisher
Infectious environment (Yes/No)	Infectious Environment	No Infections declared
Labor force (Family, Non-Family)	Family Labor Force	Non-Family Labor Force
Number of barns (One ; two or more)	One Barn Only	Two Barns or more
Stall age (<5 years, >5 years)	Recent Stall <5 years	Older Stall >5 years
Number of animals placed (<500, >500)	Small Facility	Medium/Large Facility
Materials used to build the barn (Masonry, Wood, Mixed) b)	Optimal Barn Materials	General Barn Materials
Roof material (Clay; Asbestos; Zinc) b)	Optimal Roof Materials	General Roof Materials
Barn position relative to the sun (Diagonal; Contrary; Parallel)	Sun Parallel Oriented	No Defined Sun Orientation
Trees around the facilities (Yes/No)	Farm with Trees	No Trees
Floor type (Solid, Fully slatted, Partially slatted) a)	Fully Slatted	Partially Slatted
Building type (Mechanically ventilated, Naturally ventilated, Automatic control of natural ventilation, Climate respiratory chamber) a)	Mechanic Ventilation, Automated Ventilation Control	Natural Ventilation
Humidifiers/nebulizers (Yes/No)	With Nebulizers	Without Nebulizers
Pigs per feeder	Unsufficient Feeders	Sufficient Feeders
Feed Allowance (Ad libitum, Restricted)	Restricted Feed Allowance	Ad libitum Feed Allowance
Feeder model (Conical automatic, others) b)	Optimal Feeders	General Feeders
Feeder space (cm2)	Unsufficient Feeder Space	Sufficient Feeder Space
Drinker model (Nipple, Water cup, at Feeder) b)	Optimal Drinkers	General Drinkers
Drinker space (cm2)	Unsufficent Number of Drinkers	Sufficent Number of Drinkers
Treated Water (Yes/No)	Untreated Water	Treated Water
Bedding (Yes/No)	With Bedding	Without Bedding
Number of animals per pen (<20, >20)	Large Pens	Small Pens
Pens with shallow pools (Yes/No)	Pens with Shallow Pools	Pens Without Shallow Pools

Table 14 – Farm Characteristics Tags

Notes:

a) Unused features were considered very uncommon

b) Identified features were too many, opted for the categorization of “optimal” or ”general”

IoT Sensors

This is the data obtained from the IoT sensors already provided by Farmcontrol's solution. Here is a list of possibilities:

Dimension	Metrics	IoT Sensors
Ambient Conditions	Temperature Inside (Average, Max, Min)	Temperature Sensor
	Temperature Outside (Average)	Temperature Sensor/Web Subscription
	Relative Humidity (Average, Max, Min)	Humidity Sensor
	Dust concentration	Quality of Air Sensor
	Ammonia concentration	Ammonia Sensor
Animal Weight	Weight (Kg)	Automated Animal Scale
	Number of Weighings	
	Uniformity	
	Average Daily Weight Gain (g/day)	
Environment	Energy Consumption	Energy Consumption Sensor
	Water Consumption	Water Meter Sensor
Installations	Lighting regime (h/day)	Light Sensor

Table 15 – IoT Sensors data possibilities in Farmcontrol

Production KPIs

These are the production batch KPIs that will be calculated on the presented batch screen, pdf batch reports or dashboard widgets:

Livestock Production Batch KPI's	Formula	Source of Data
Feed Conversion Ratio (kg)	(Total Entries of Feed - Total Exits of Feed) / (Total Weight of Animal Exits - Total Weight of Animal Entries)	Animal and Feed Movement Records
Average Daily Weight Gain (g/day)	(Average Weight of Animal Exits - Average Weight of Animal Entries) / Batch Age	Animal Movement Records, Autom.Animal Scale
Average Daily Feed Consumption (Kg/day)	(Total Entries of Feed - Total Exits of Feed) / Average Number of Animals in Stock / Batch Age	Feed Silo Weight Sensor, Animal and Feed Movement Records
Average Daily Water Consumption (l/day)	Total Water Consumption / Average Number of Animals in Stock / Batch Age	IoT Water Measure Sensor
Mortality Rate (%)	Number of Dead Animals / Total Number of Animals entered	Animal Movement Records
PEF - Production Efficiency Factor	[Average Weight of Animal Exits x (1 - %Mortality Rate)] / (Average Age of Animal Exits x Feed Conversion Ratio) x 100	Animal and Feed Movement Records

Table 16 – Production KPIs

4.3.5. Use Cases Architecture

One of the main goals of the production module of the Farmcontrol Platform is to provide the user with an easy way to insert all the relevant manual livestock production batch data and enrich it automatically with the sensor data, already available on the platform, to produce relevant information reports to the livestock farmer.

In the following figure, there is an overview of the software interactions the farmer will have:

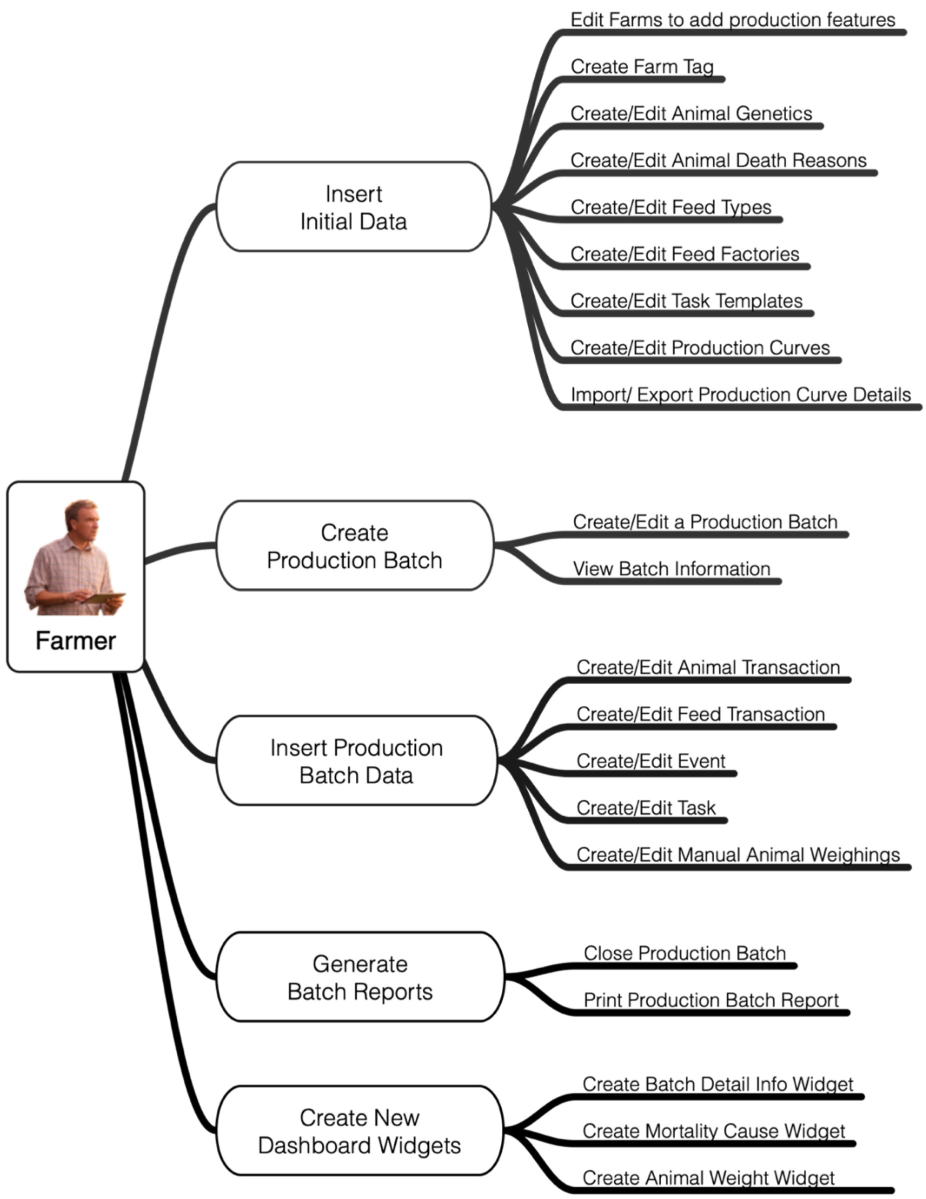


Figure 34 – Use Cases Overview

Each use case functionality is extensively described in **Annex I**.

4.4. System Design

4.4.1. Software Menu Structure

The following menu structure was set to support the new software features:

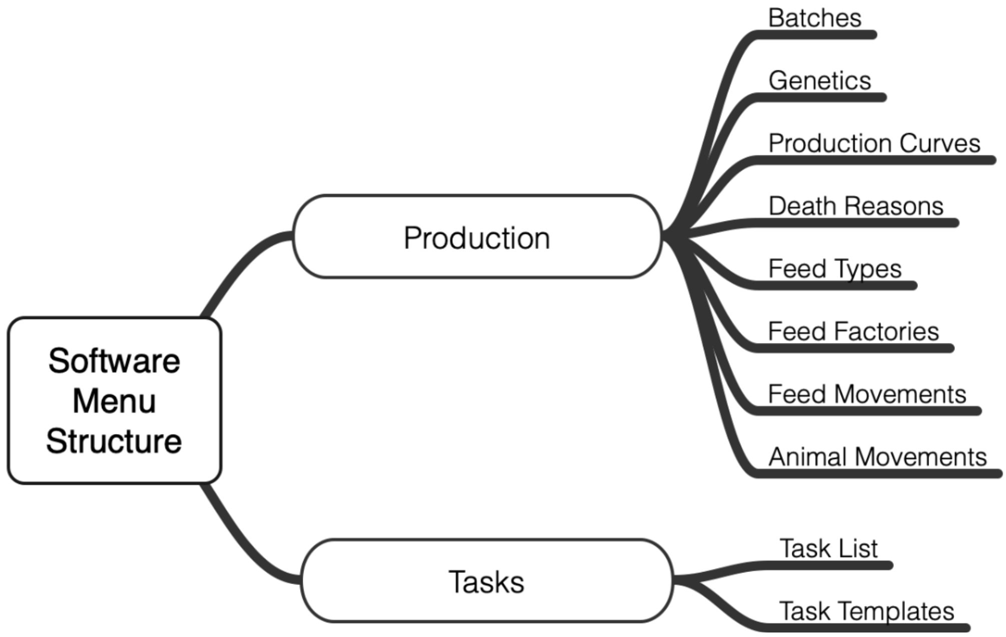


Figure 35 – Software Menu Structure

4.4.2. Description of Database Tables

The types of PostgreSQL data used are:

Data Type	Description
uuid	universally unique Identifier, a 128-bit quantity that is generated by an algorithm
varchar(n)	character variable with n limited length
text	character variable with unlimited length
jsonb	JSON format with binary representation
numeric	number up to 131072 digits before the decimal point to 16383 digits after the decimal point
integer	number from -2147483648 to +2147483647
real	number with 6 decimal digits precision
float8	number with double precision floating-point
date	date - one day resolution
timestamp	date - 1microsecond/14 digits resolution
bool	boolean data type

Table 17 – Types of PostgreSQL data used

Description of Tables (detailed description of data in Annex II):

Entities – A concept that already exists in the software and can be a Group, an enterprise, a Farm or a Sector (of the farm)

Entities Tag – A label to characterize farm features

Tag Mapping – Assigns Entities to Tags

Users – Platform Users

Tasks – Tasks to be done associated with an Entity, a production batch or both

User Task Mapping – Assigns Tasks to Users

Task Template – a repository of tasks and procedures that are usually repeated to be called when needed and avoid repetition while maintaining a global deployment

Task Categories – Types of Tasks (ex: medication)

Production Curves – Global KPIs objectives for benchmarking

Production Curves Details – Objectives for each day of age of the production batch

Production Curve Task Templates details – Assigns Task Templates to a particular age of a production curve detail in order get triggered when the batch reaches that age

Production Types – Refers to the production type. Used to categorize if the batch is for the production of meat (Growth) or other production outputs (ex: production of eggs or milk). This is needed because the data to be collected and the KPI's for each type are different.

Production Subtypes – refers to the production flow (ex: all-in/all-out or continuous)

Animal Transaction – Animal transactions on the production batch

Animal Species – the name of the species

Animal Sub-species – the stage of production of each specie (ex: Fattening, First Phase, etc.)

Animal Genetics – the genetic used on the production batch

Animal Death Reasons – Description of death reasons

Death Reasons Categories – Categories of Death Reason for statistics integration

Feed Transaction – Feed Transactions on the production batch

Feed Types – Feed type used

Feed Factories – Origin of the feed on the production Batch

4.4.3. Conceptual Database Design

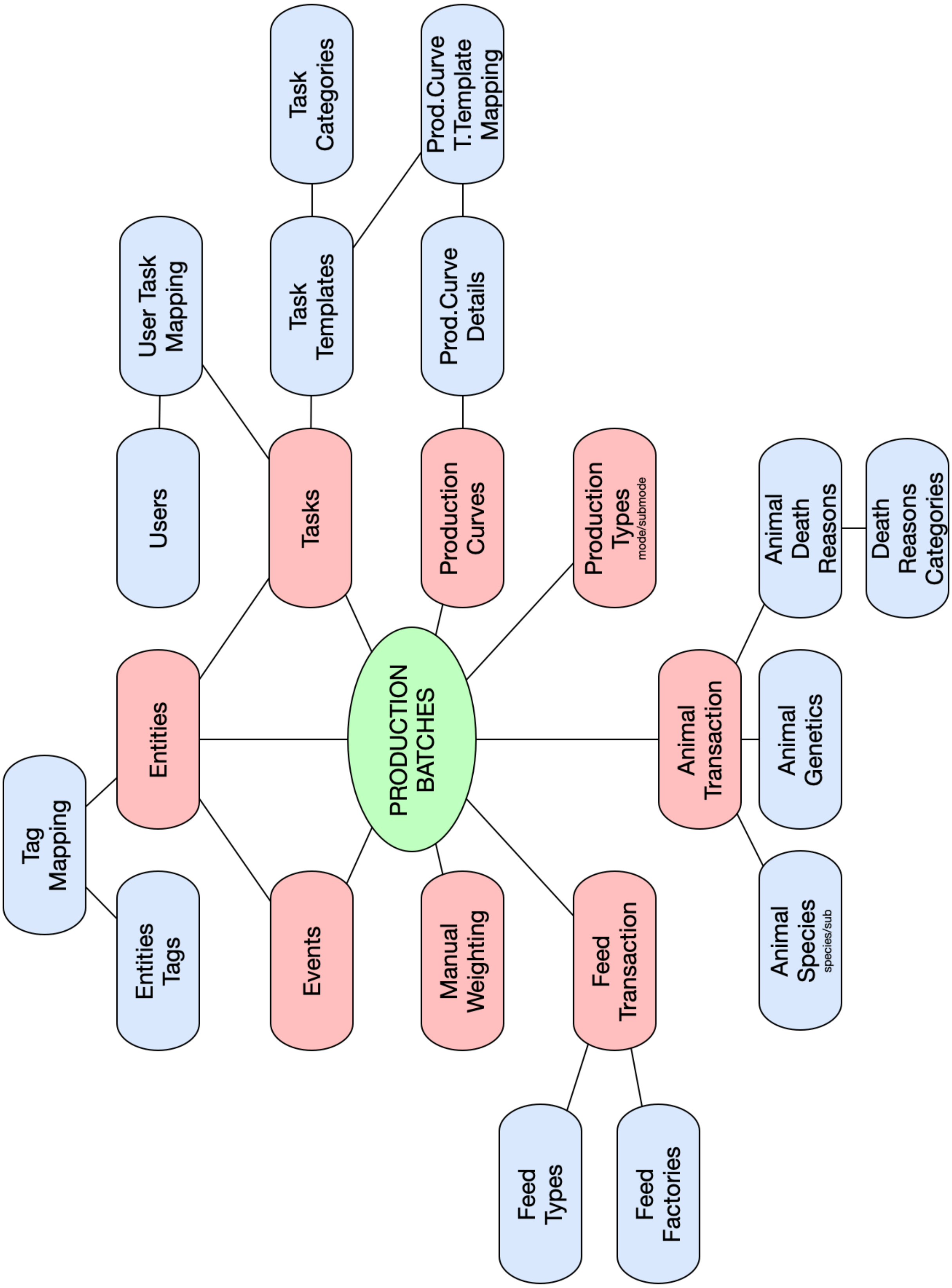


Figure 36 – Conceptual Database Design

4.4.4. Database Diagram

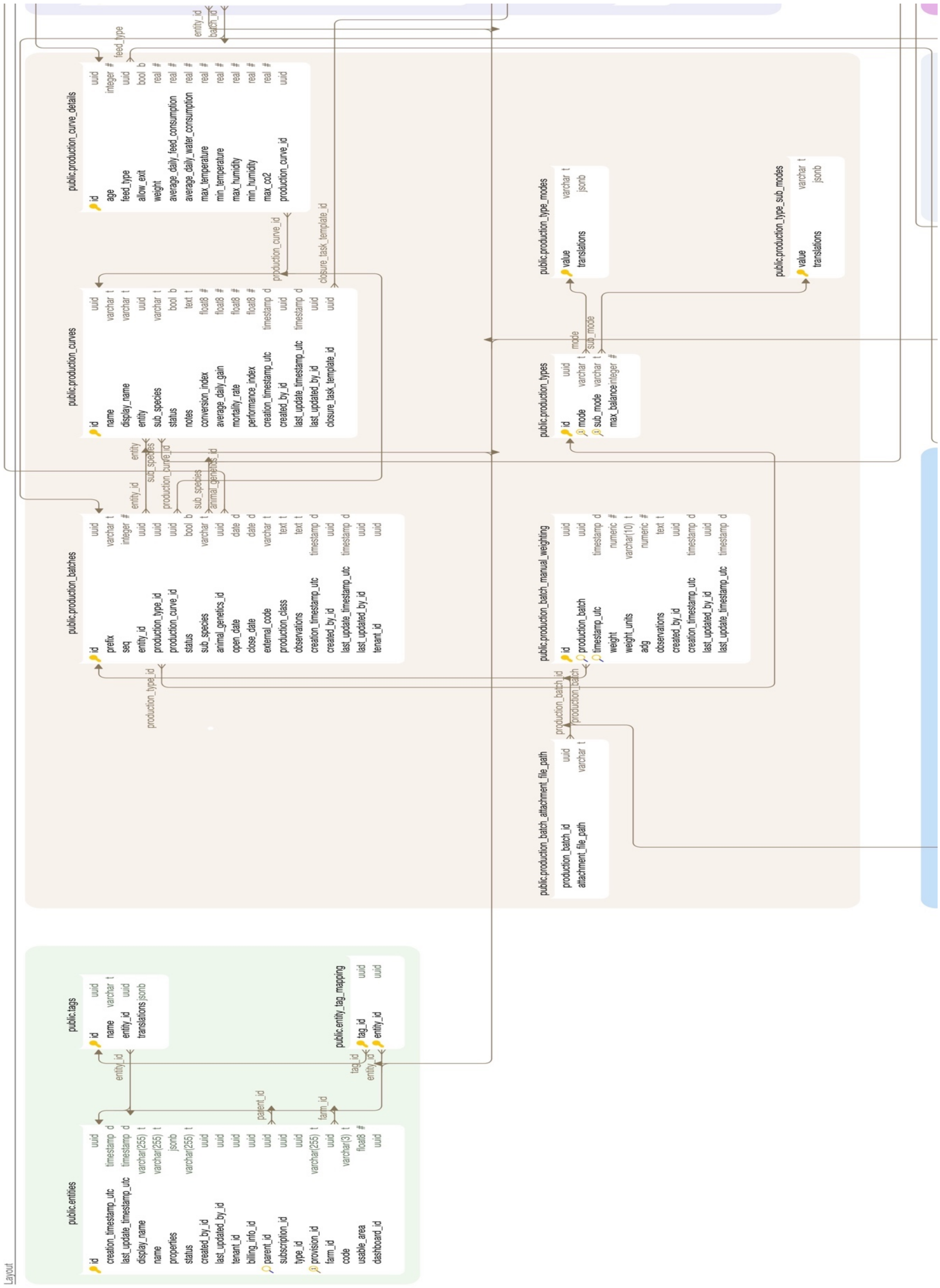


Figure 37 – Database Diagram

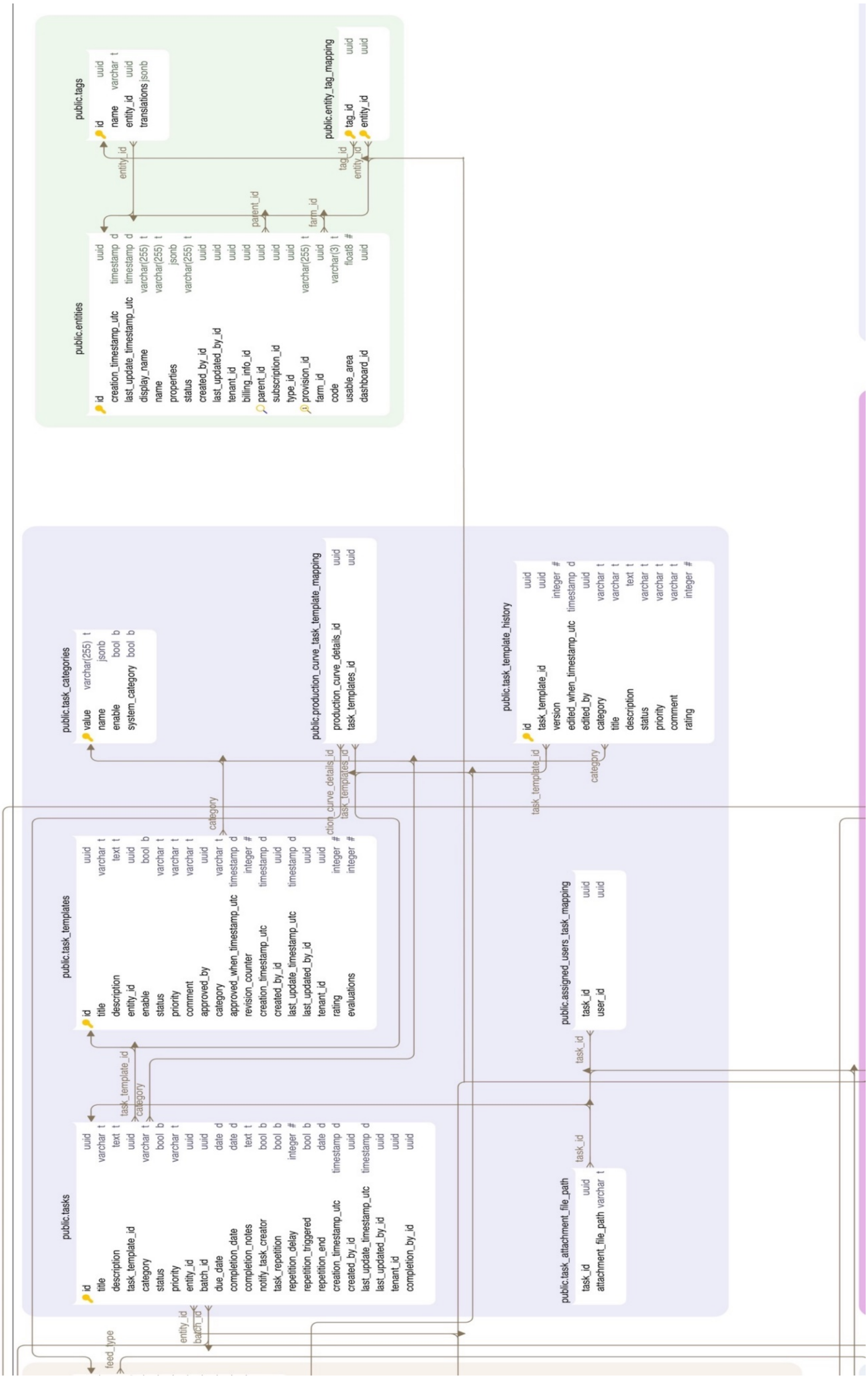


Figure 38 – Database Diagram (continued)

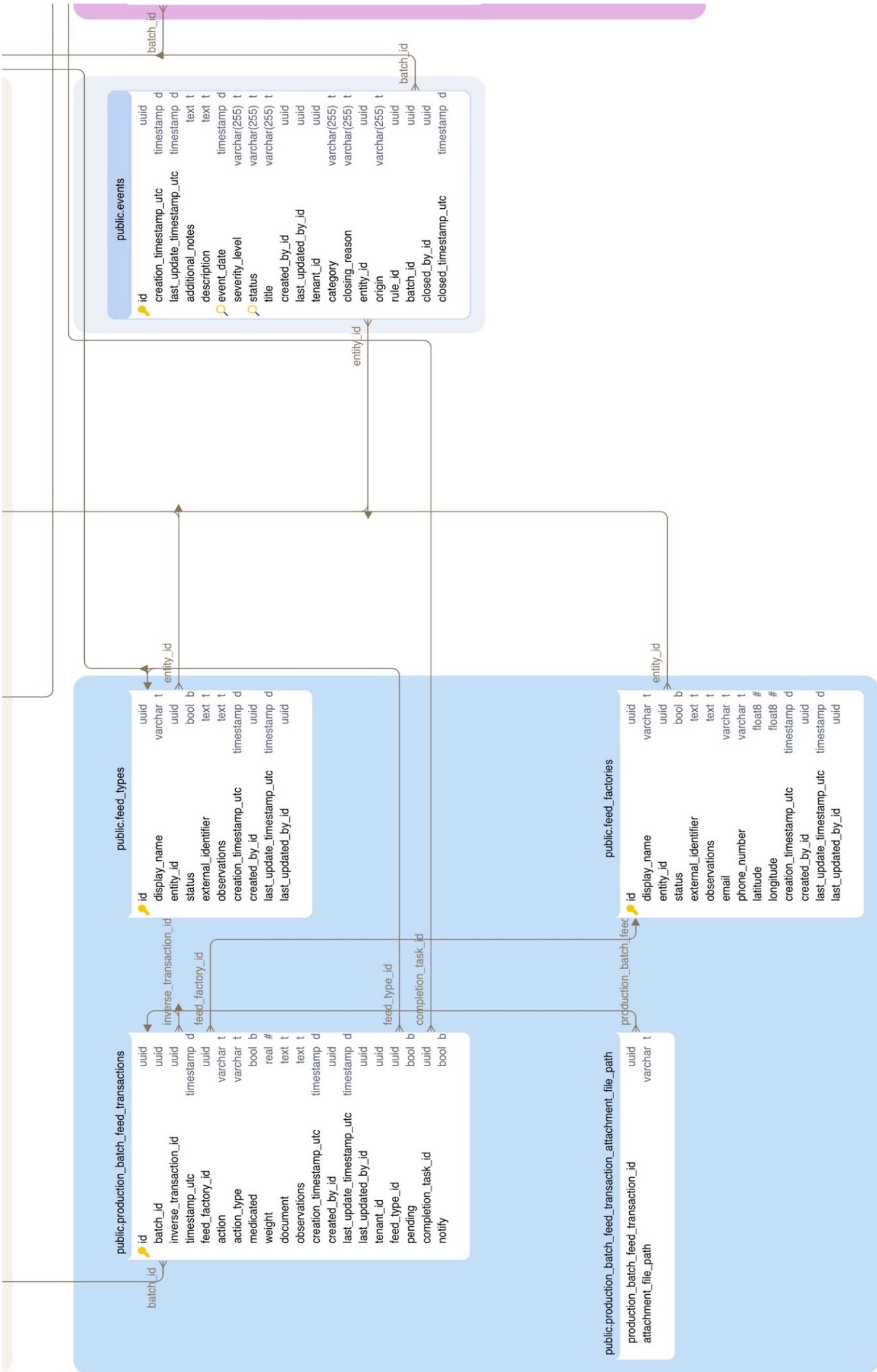


Figure 39 – Database Diagram (continued)

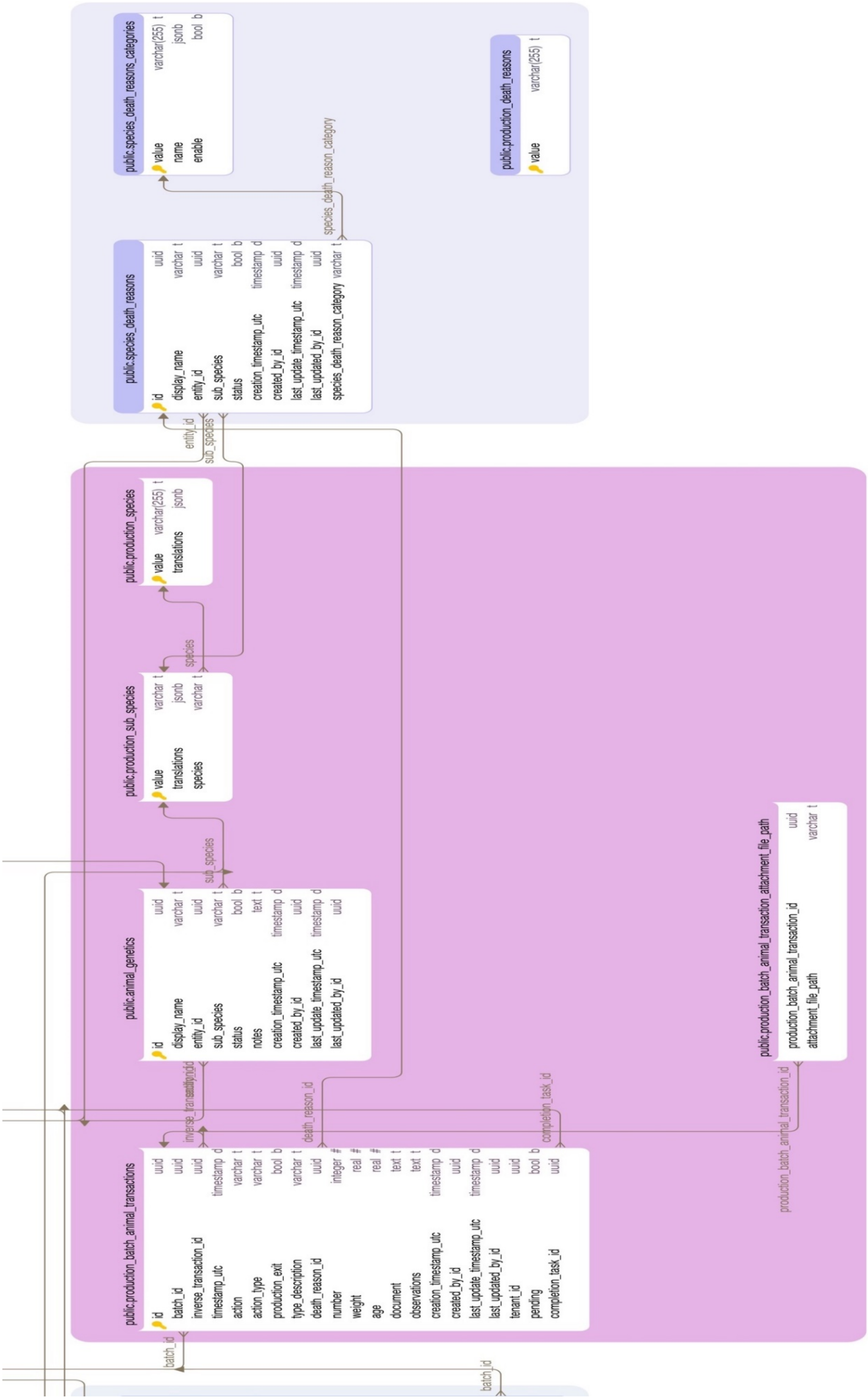


Figure 40 – Database Diagram (continued)

4.4.5. Software User Screens

Main Menu / Shortcuts Button

With the new module, the software gained two new menus for the new functionalities: “Tasks” and “Production”. Also, a new shortcuts button was added to the top bar to provide easier access to commonly used manual daily inputs to the software.

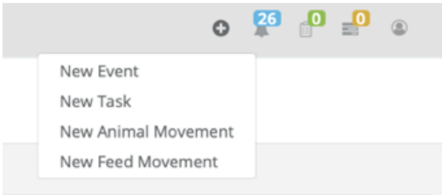


Figure 41 – Top Bar Shortcuts Button

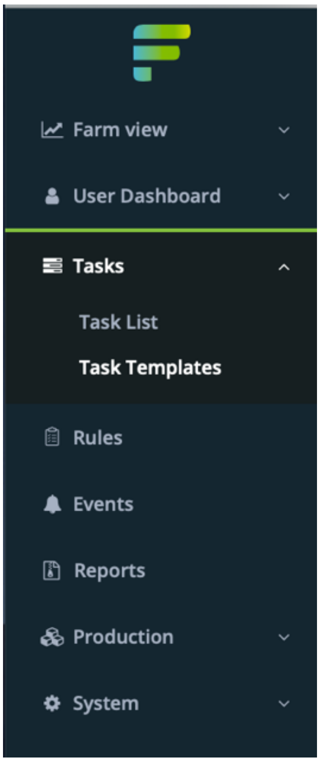


Figure 42 – Tasks Main Menu

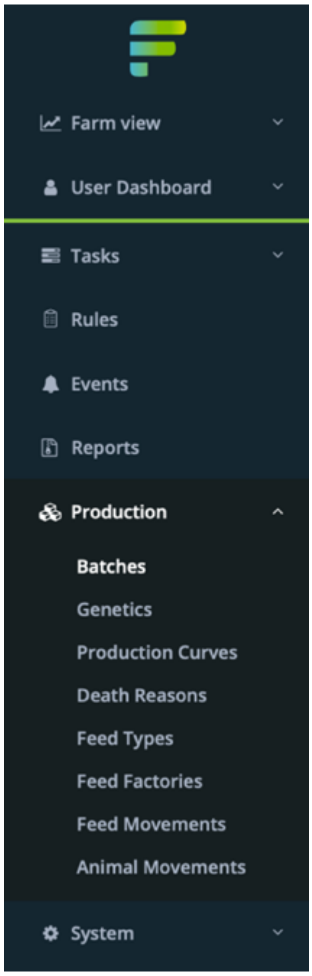


Figure 43 – Production Main Menu

Enterprise / Farm Entities Management

The Entity edit screen was updated on Farm Sectors to provide information on new relevant data, such as Characterization Tags, Usable Area for Animals and Default IoT Interfaces to correlate sensor data with production batch details.

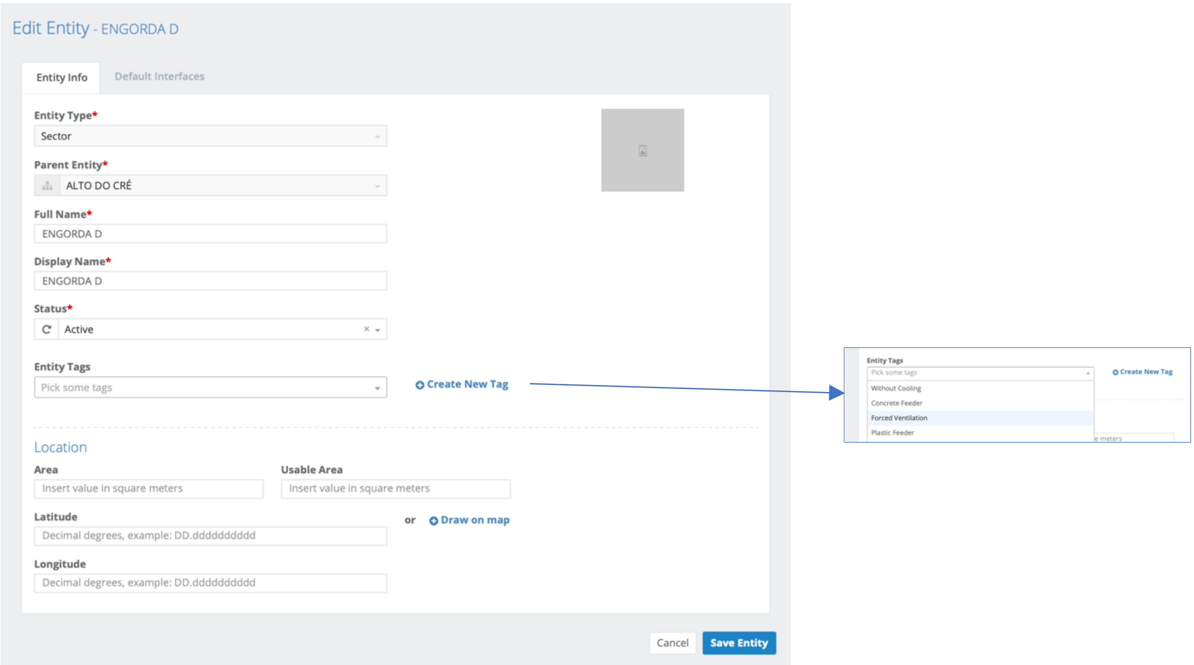


Figure 44 – Farm Sector Entity Edit & Tag Creation (Page 1) /Tags Drop Menu (UC#1&2)

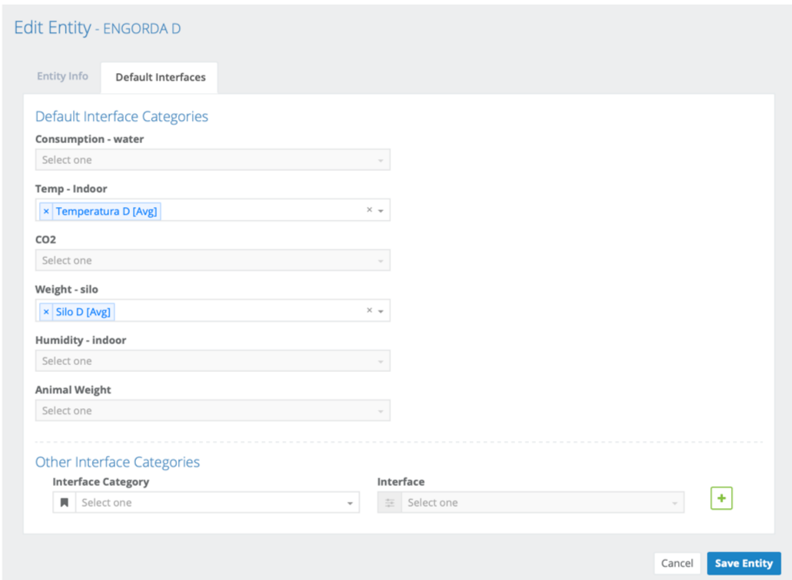


Figure 45 – Farm Sector Entity Edit (Page 2) (UC#1)

Management of Production Batches

Here the user can manage the Production Batches he has access to, where there are all records regarding animal and feed movements, manual inputs, tasks, events. The "Batch View" dashboard is where farm sensor data can be seen in the context of batch metadata.

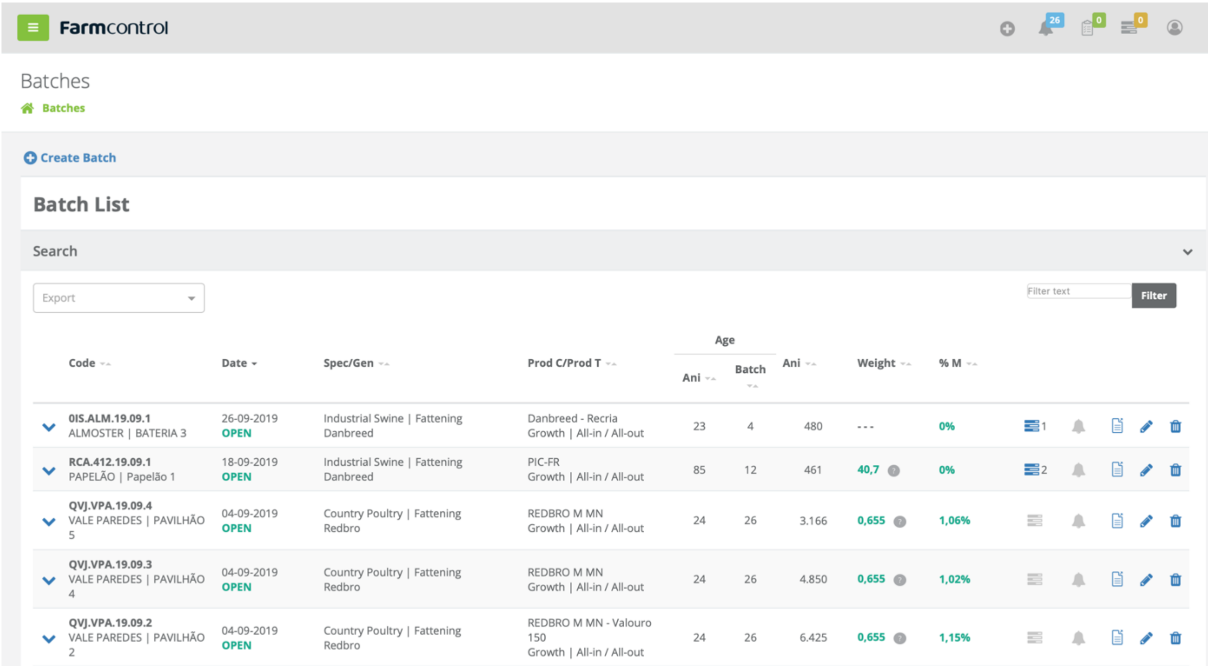


Figure 46 – Production Batch List (UC#10)

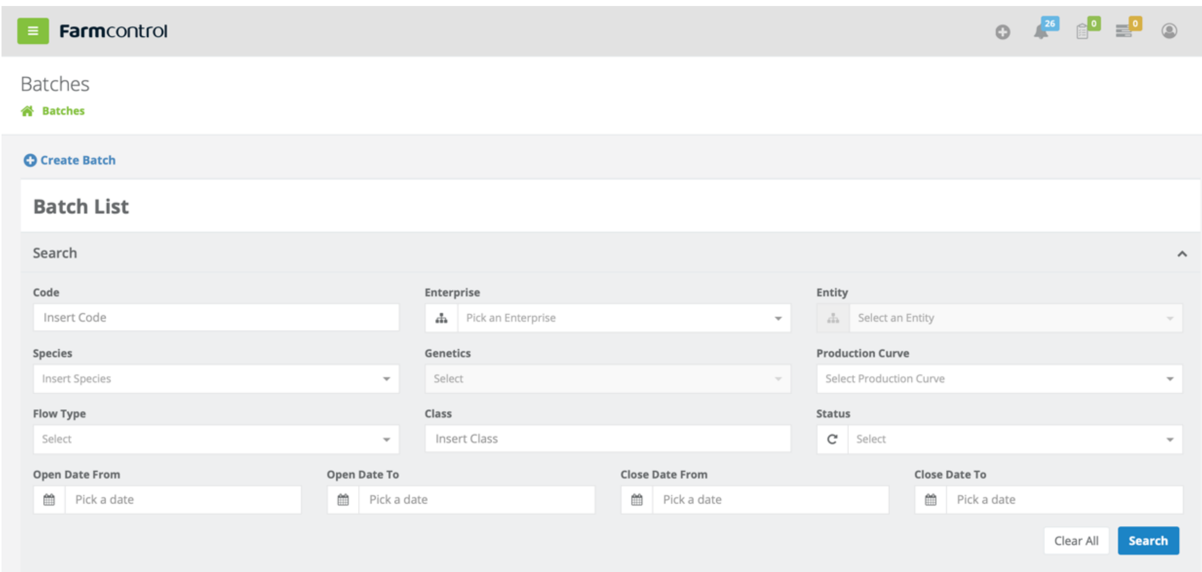


Figure 47 – Batch List Search Menu (UC#10)

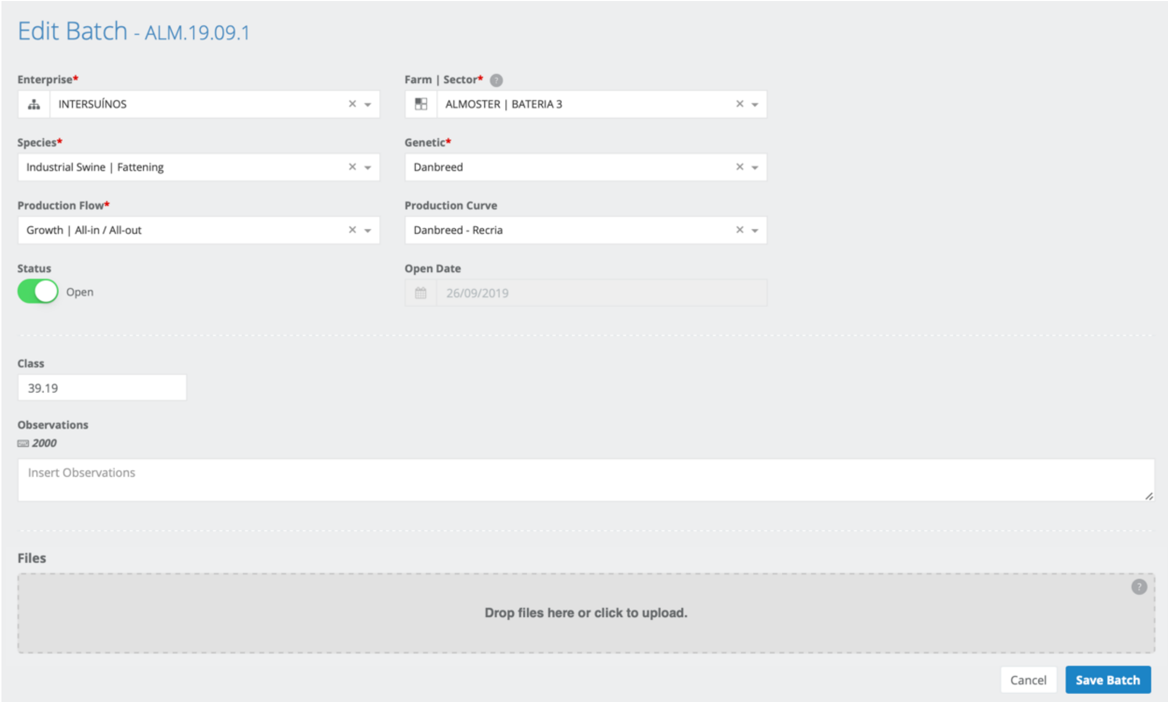


Figure 48 – Batch Create/Edit Screen (UC#10)

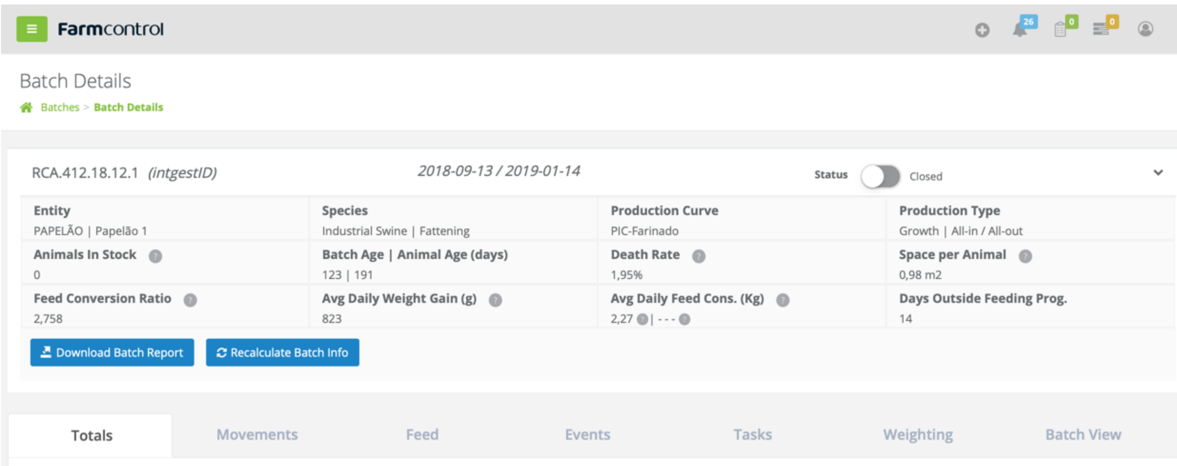


Figure 49 – Batch Details Main Screen (UC#11/UC#17/UC#18)

Figure 50 – Batch Details Totals Tab (UC#11)

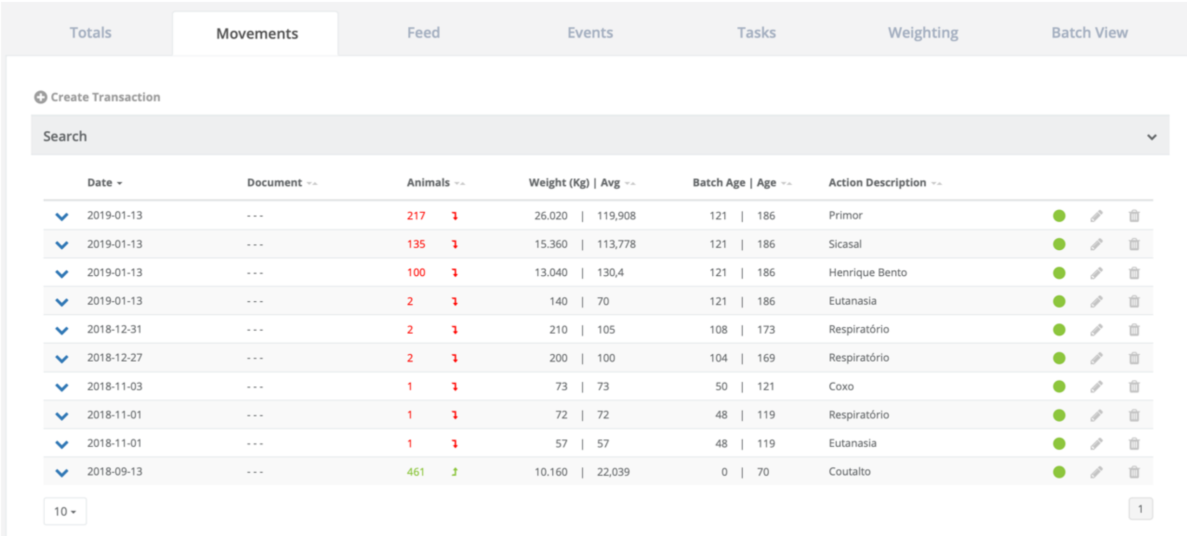


Figure 51 – Batch Details Animal Movements Tab (UC#11)

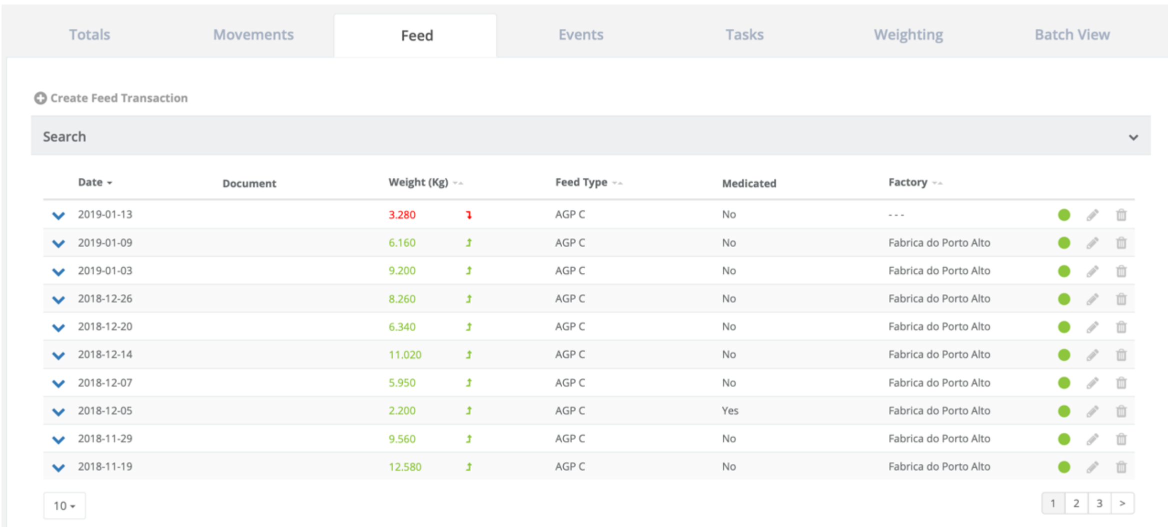


Figure 53 – Batch Details Feed Movements Tab (UC#11)

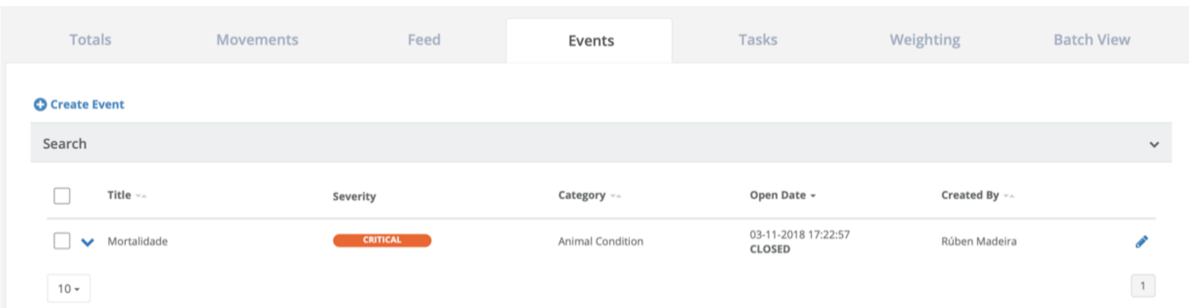


Figure 52 – Batch Details Events Tab (UC#11)

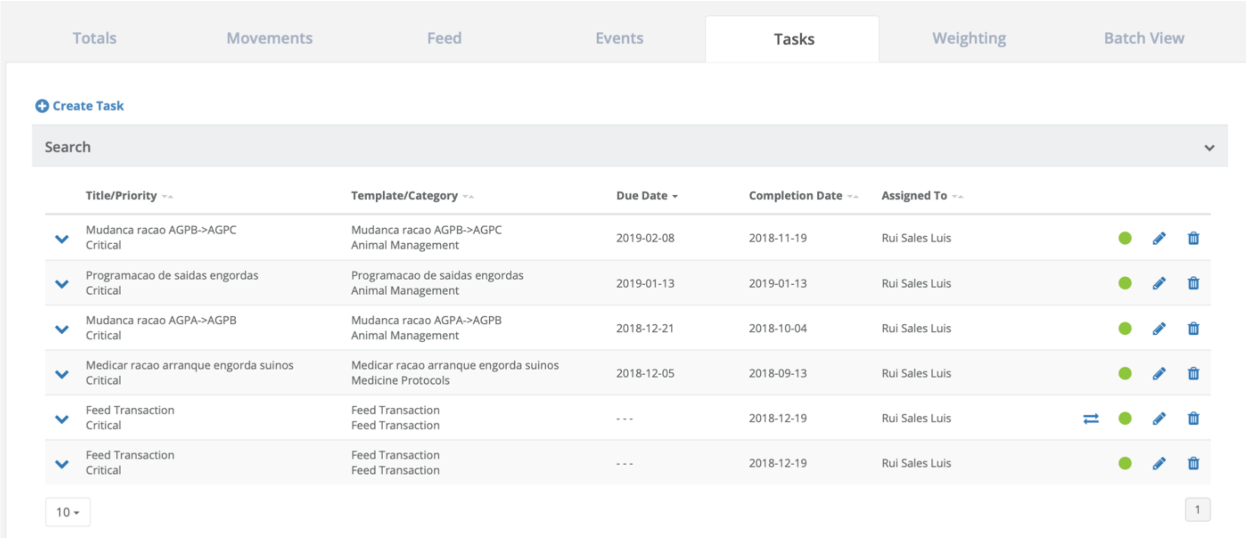


Figure 54 – Batch Details Tasks Tab (UC#11)

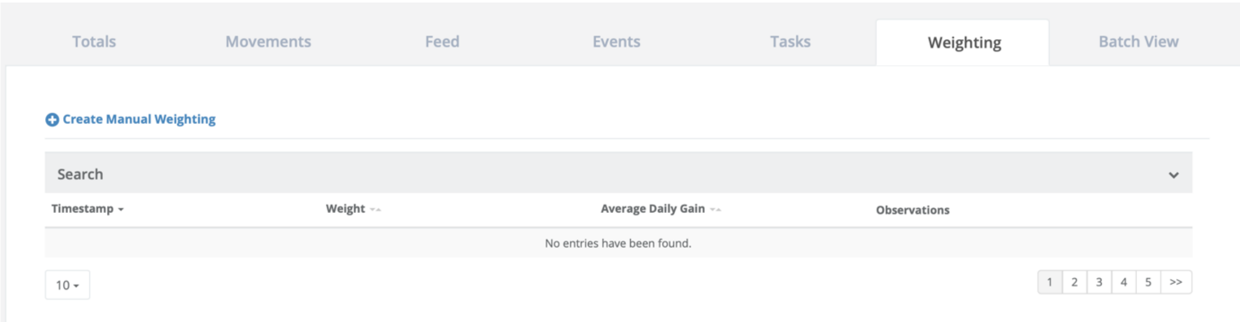


Figure 55 – Batch Details Manual Weights Tab (UC#11)

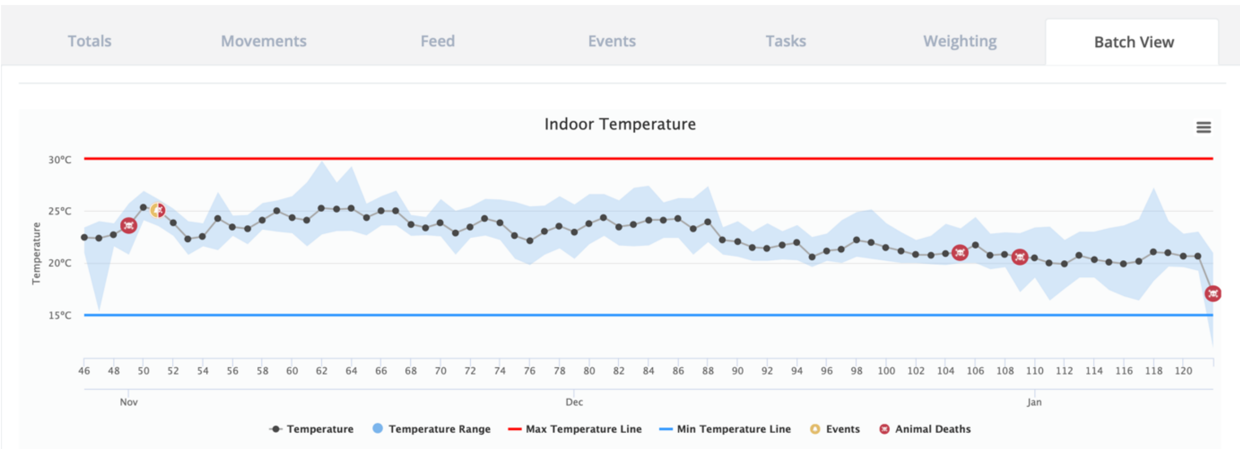


Figure 56 – Batch View Temperature Graph (UC#11)

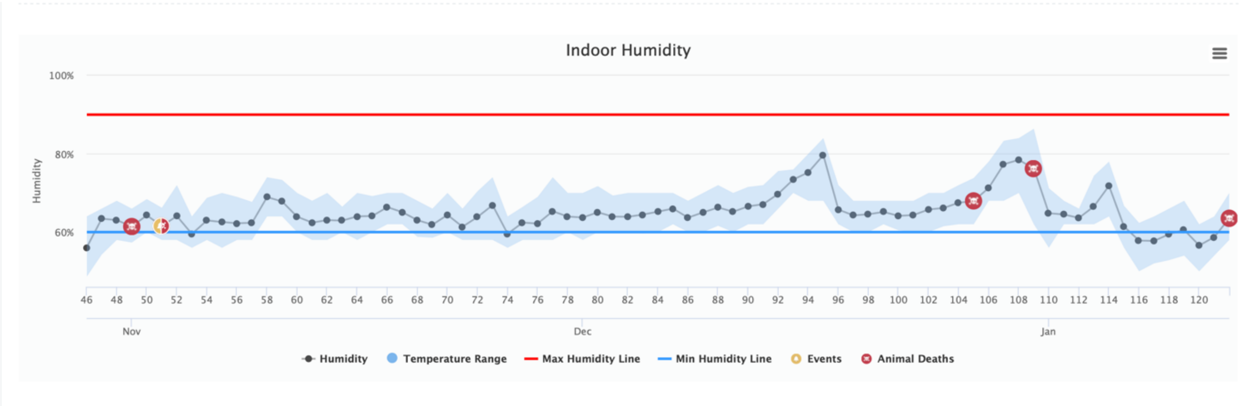


Figure 57 – Batch View Humidity Chart (UC#11)

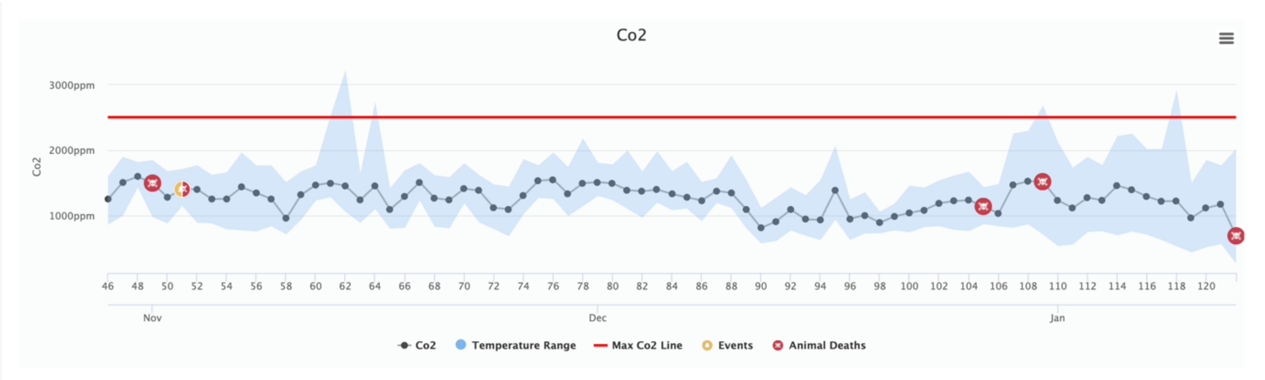


Figure 58 – Batch View CO_2 Chart (UC#11)

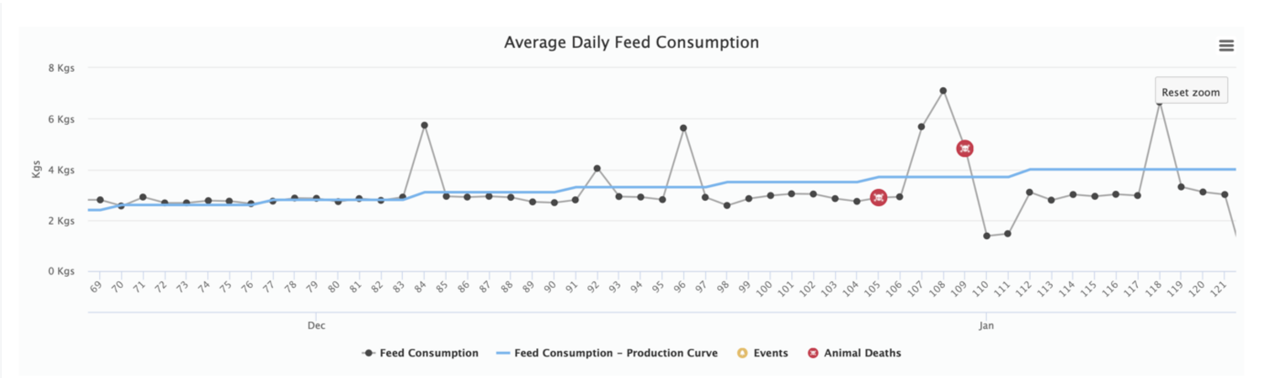


Figure 59 – Batch View Feed Consumption Chart (UC#11)

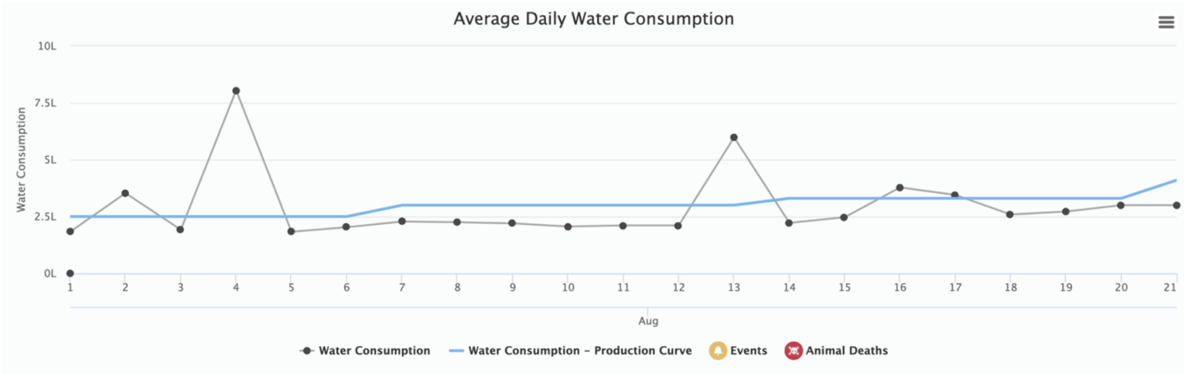


Figure 60 – Batch View Water Consumption Chart (UC#11)

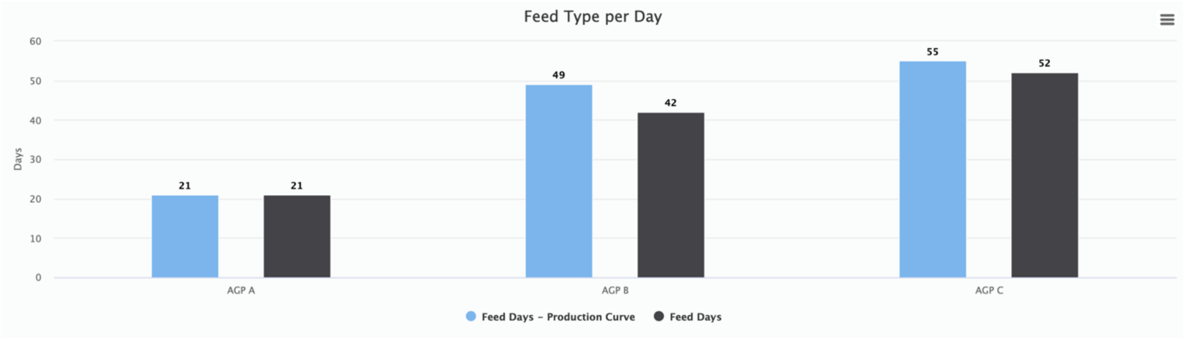


Figure 61 – Batch View Feed Program Chart (UC#11)

The Entity doesn't have default Indoor Temperature Interface
The Entity doesn't have default Indoor Humidity Interface
The Entity doesn't have default CO2 Interface
The Entity doesn't have default Weight-Silo Interface
The Entity doesn't have default Water Consumption Interface

Figure 62 – Batch View Text when no sensors are allocated to a Farm (UC#11)

Figure 63 – Batch View Slideshow for Manual Events with Pictures (UC#11)

Genetics

Users can manage different types of genetics as an important signal to animal performance data.

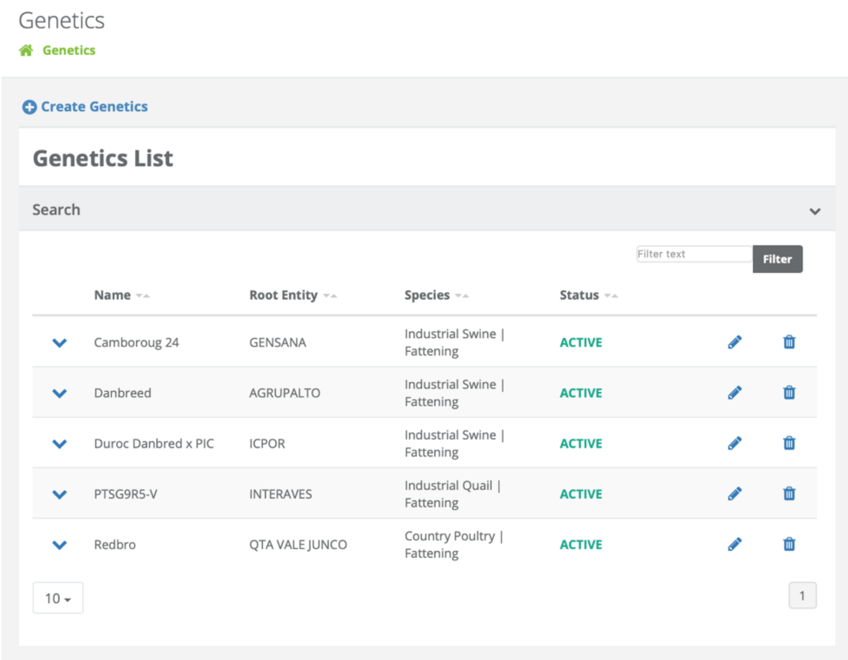


Figure 64 – Genetics List (UC#3)

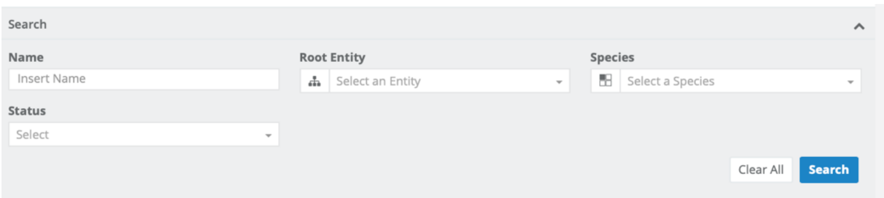


Figure 65 – Genetics List Search (UC#3)

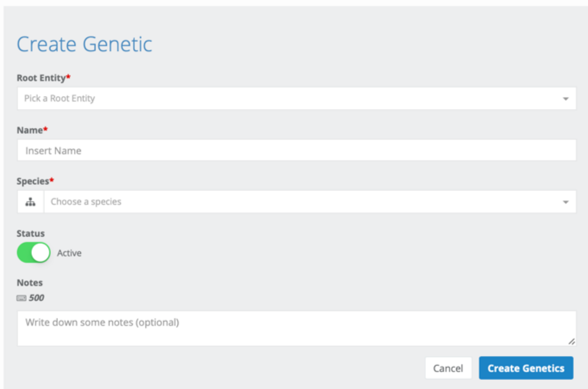


Figure 66 – Create Genetic Screen (UC#3)

Production Curves

Users can create multiple Production Curves to set performance benchmarks for production and animal welfare.

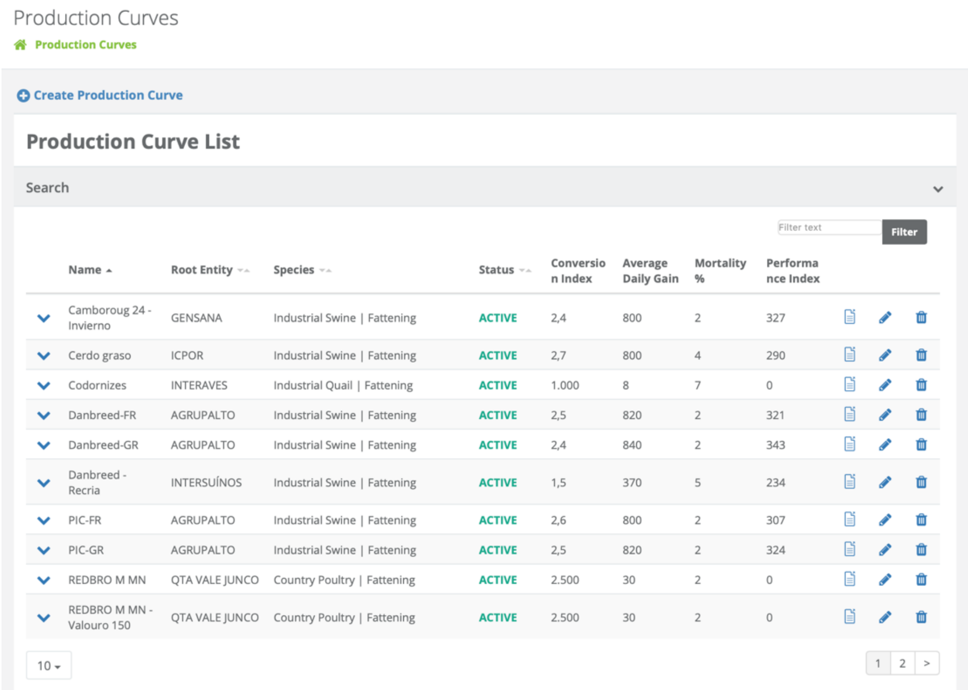


Figure 67 – Production Curve List (UC#8)

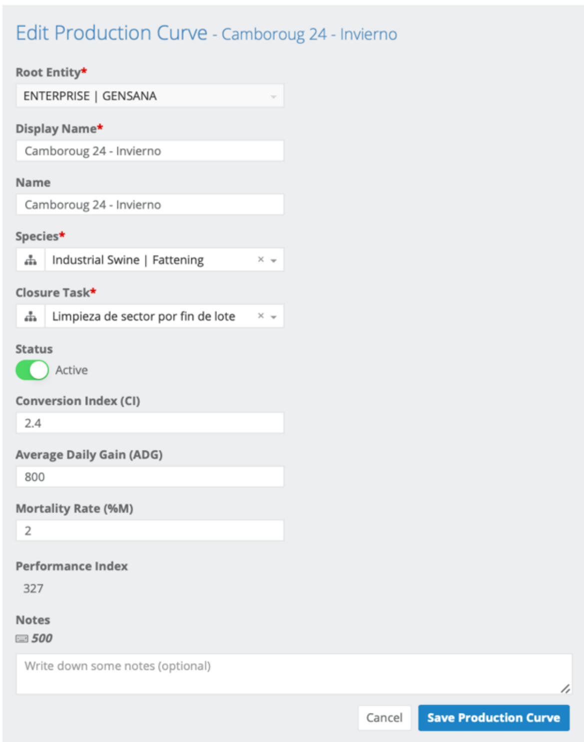


Figure 68 – Edit Production Curve Screen (UC#8)

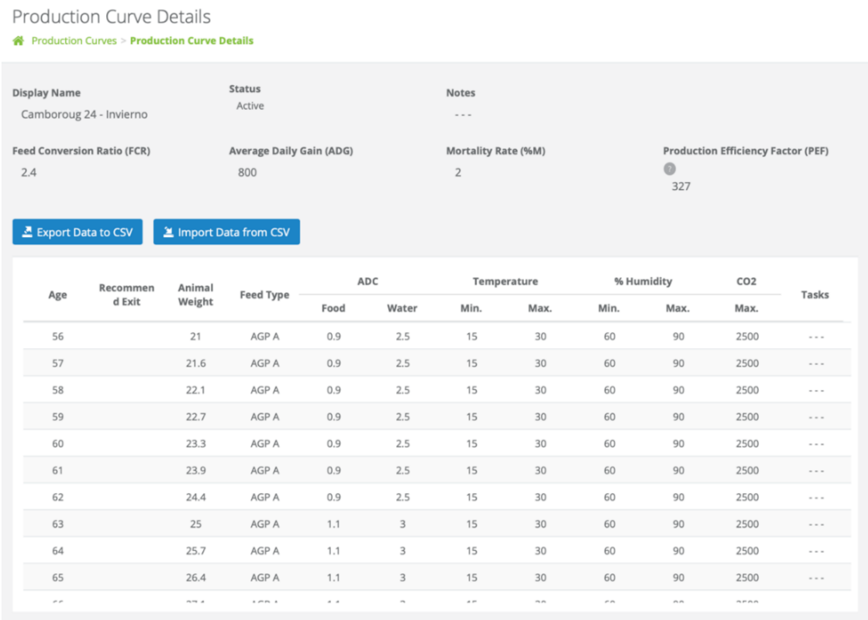


Figure 69 – Production Curve Details Screen (UC#9)

Death Reasons

Users can manage multiple animal death reasons using pre-determined categories.

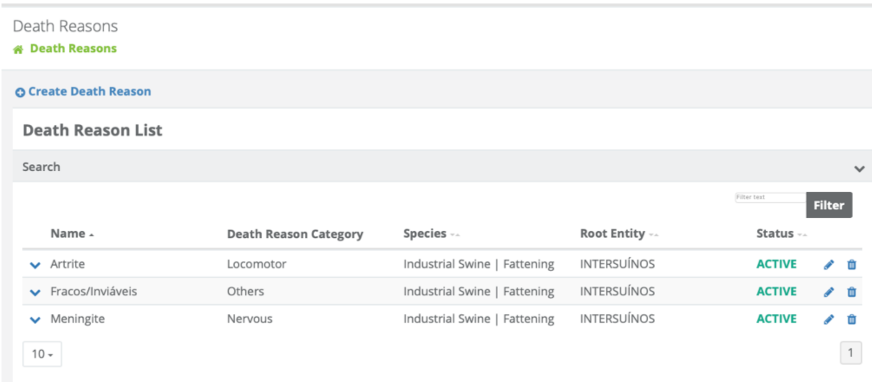


Figure 70 – Death Reason List Screen (UC#4)

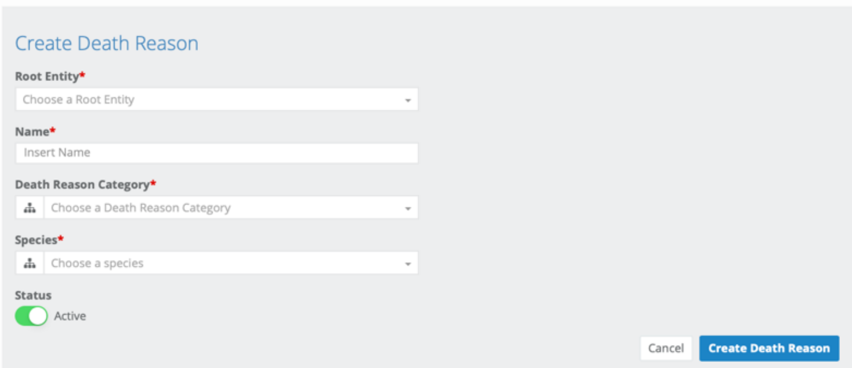


Figure 71 – Create Death Reason Screen (UC#4)

Feed Factories

Users can manage multiple feed factories to determine accurate animal feed origin.

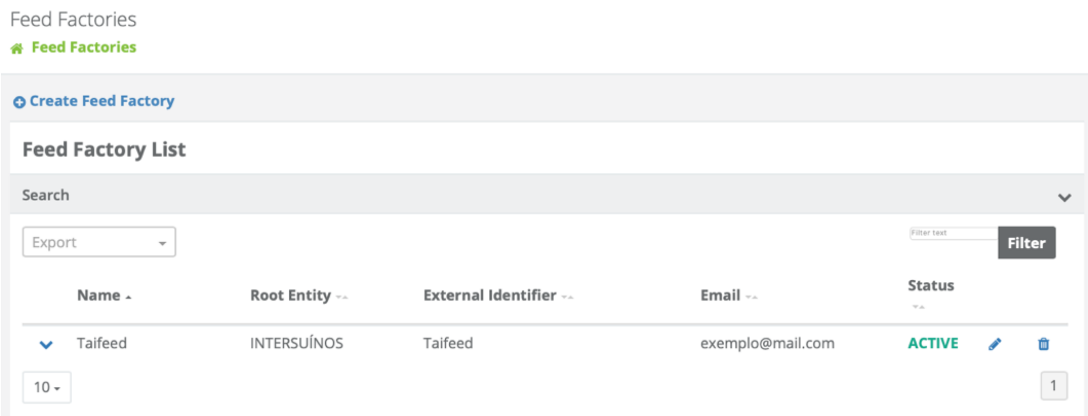


Figure 72 – Feed Factory List Screen (UC#6)

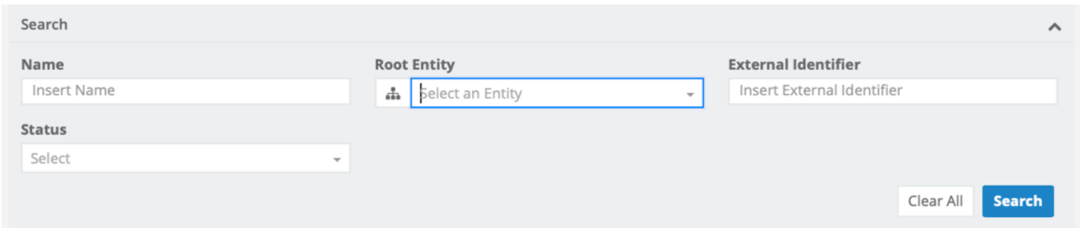


Figure 73 – Feed Factory Search Screen (UC#6)

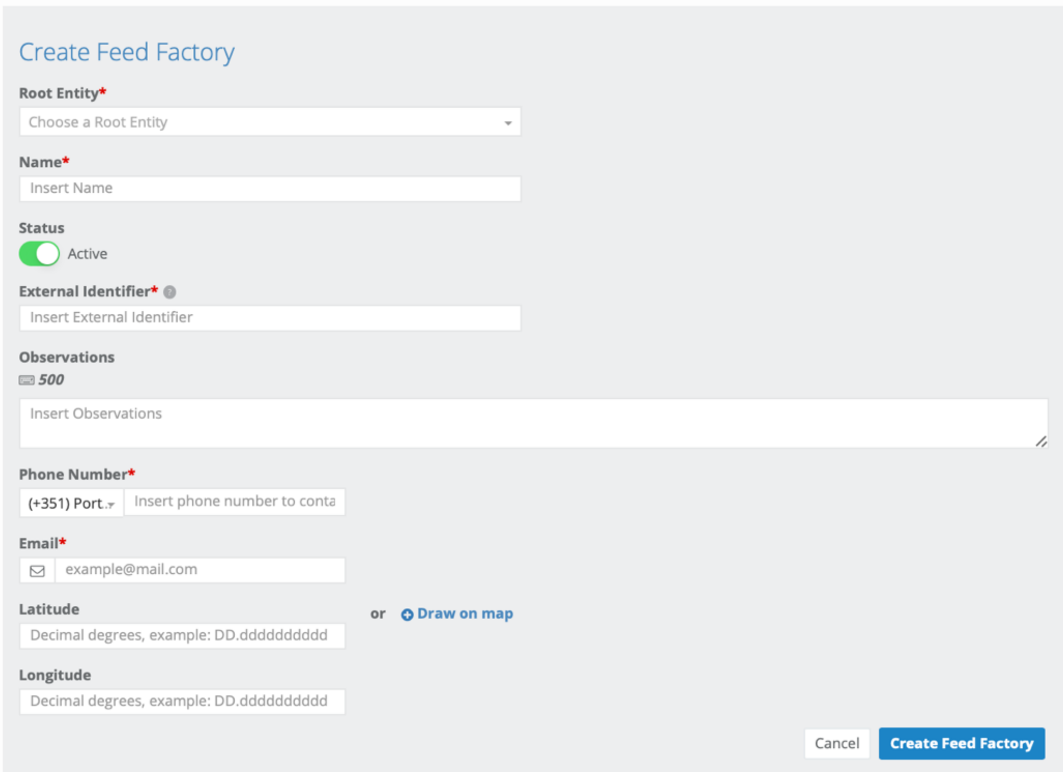


Figure 74 – Create Feed Factory Screen (UC#6)

Feed Types

Users can manage multiple feed types in order to keep track of animal feed program and traceability.

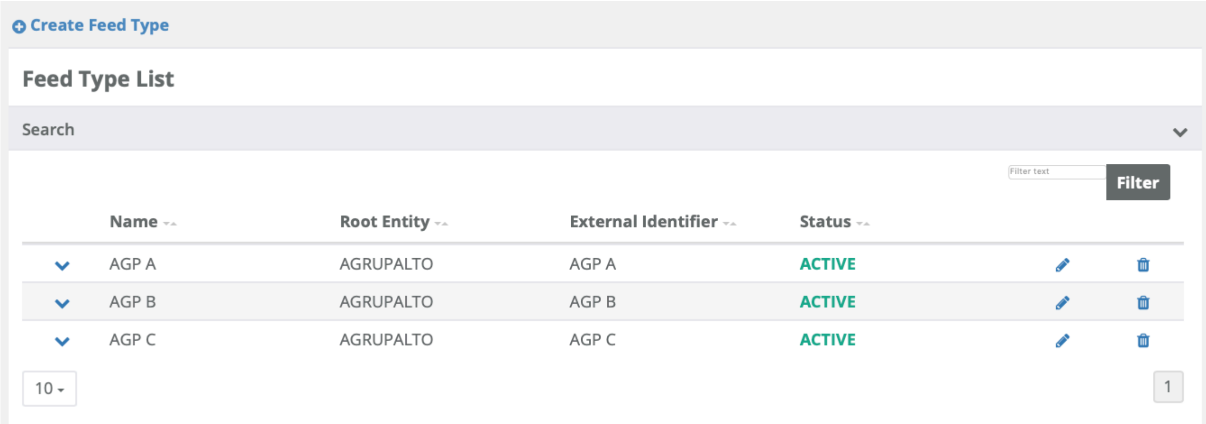


Figure 75 – Feed Type List (UC#5)

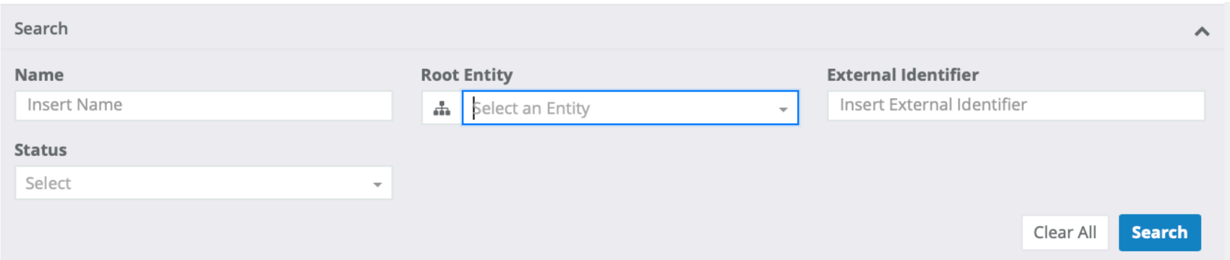


Figure 76 – Feed Type Search Screen (UC#5)

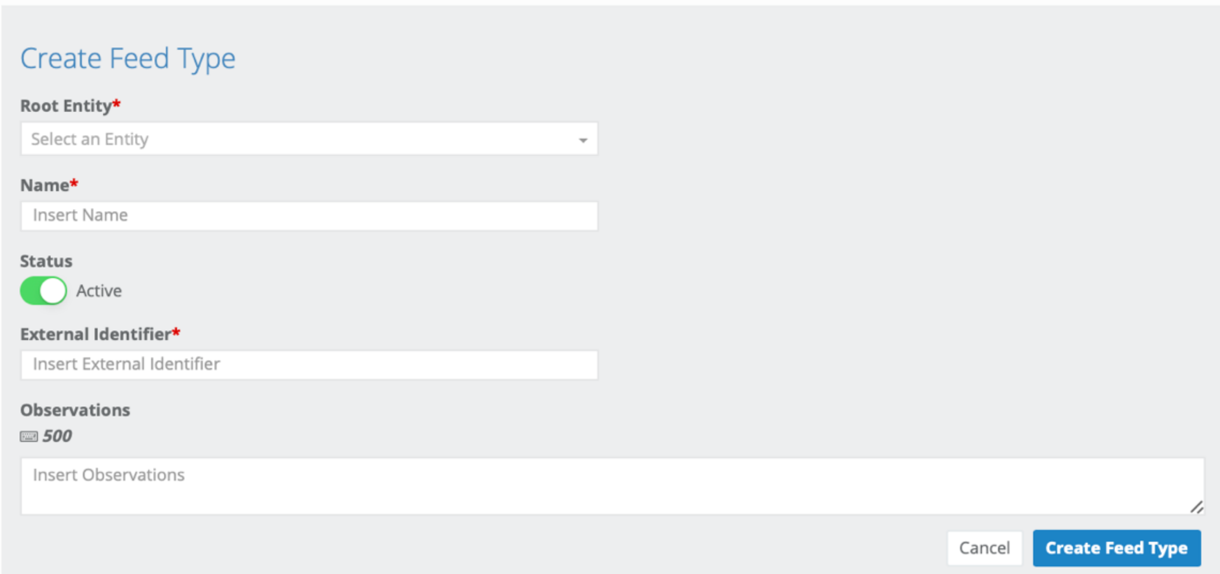


Figure 77 – Create Feed Type Screen (UC#5)

Feed Movements

Users can insert records of all animal feed movements.

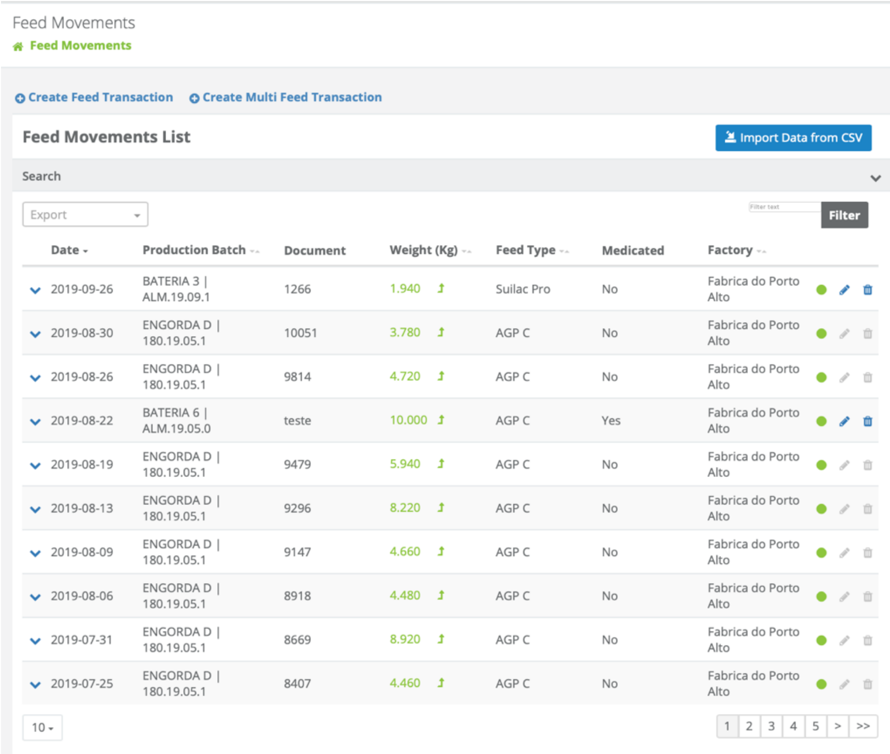


Figure 78 – Feed Movements List (UC#13)

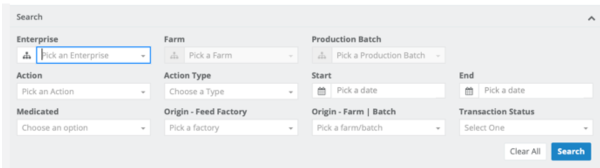


Figure 79 – Feed Movements Search Screen (UC#13)

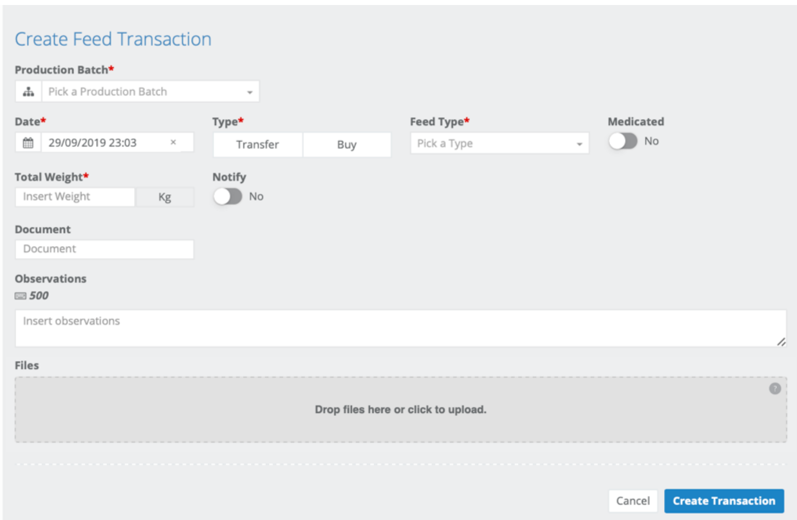


Figure 80 – Create Feed Transaction Screen (UC#13)

Animal Movements

Users can insert records of all animal transactions, such as entries, deaths, sales or transfers.

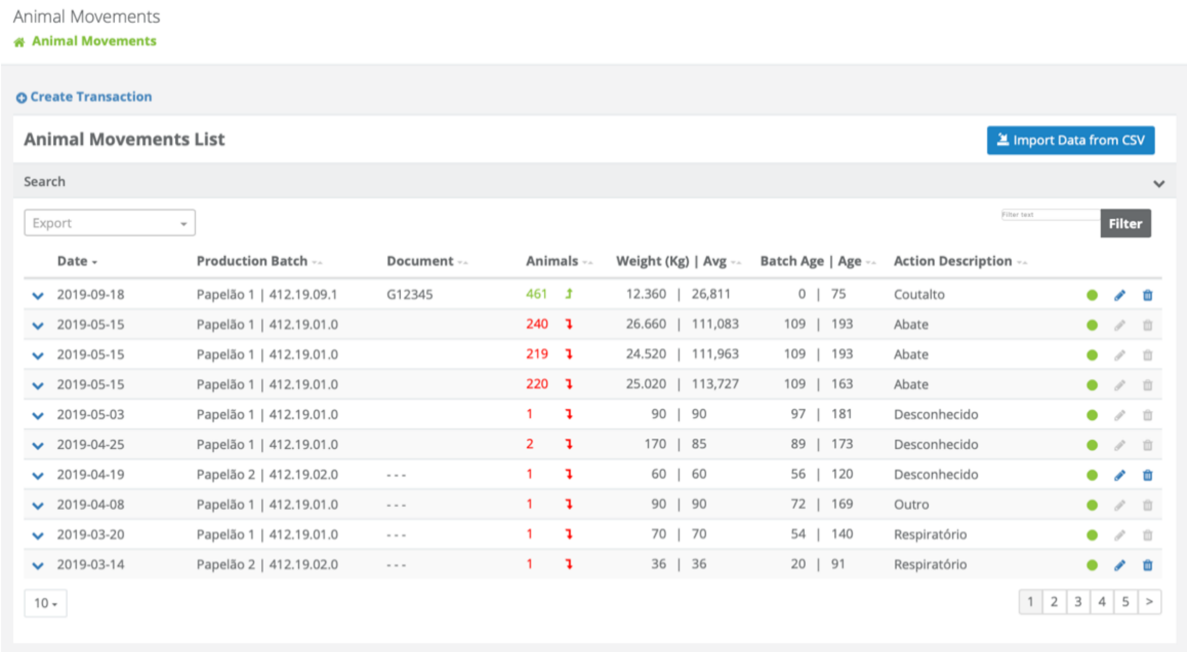


Figure 81 – Animals Movements List (UC#12)

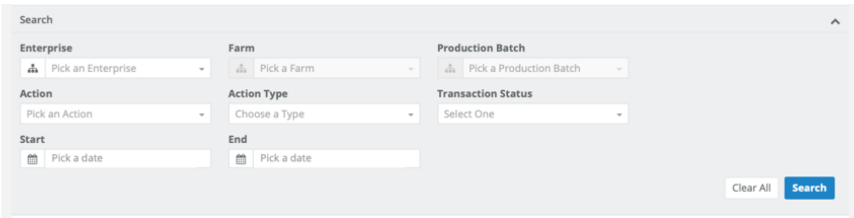


Figure 82 – Animal Movements Search Screen (UC#12)

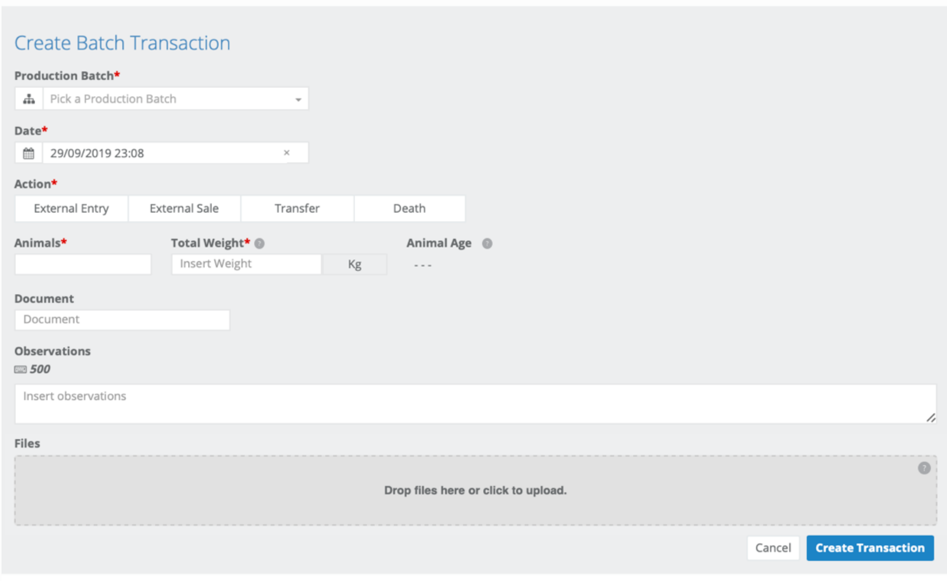


Figure 83 – Create Batch Animal Transaction Screen (UC#12)

Manual Events

Users can collect data from manual events to assure full traceability in production batches. Events can be easily categorized for further data exploration.

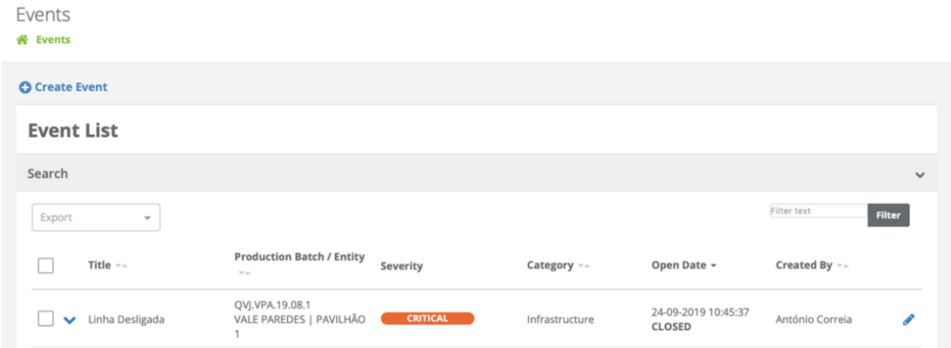


Figure 84 – Event List Screen (UC#14)

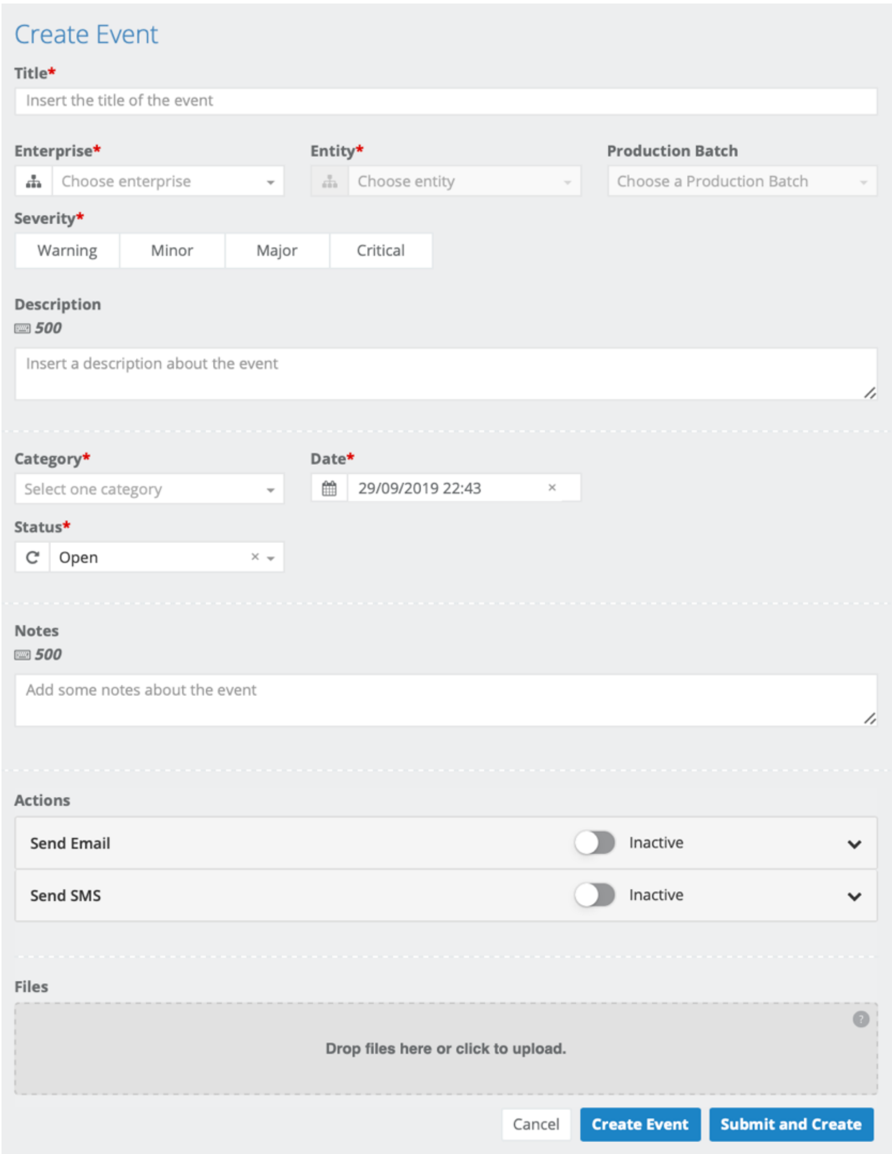


Figure 85 – Manual Event Creation Screen (UC#14)

Tasks

Users can record pre-determined tasks to help them manage daily farm records and assure full traceability in production batches. Tasks that are commonly used or tasks that are suggested by employees can be managed as “Task Templates”.

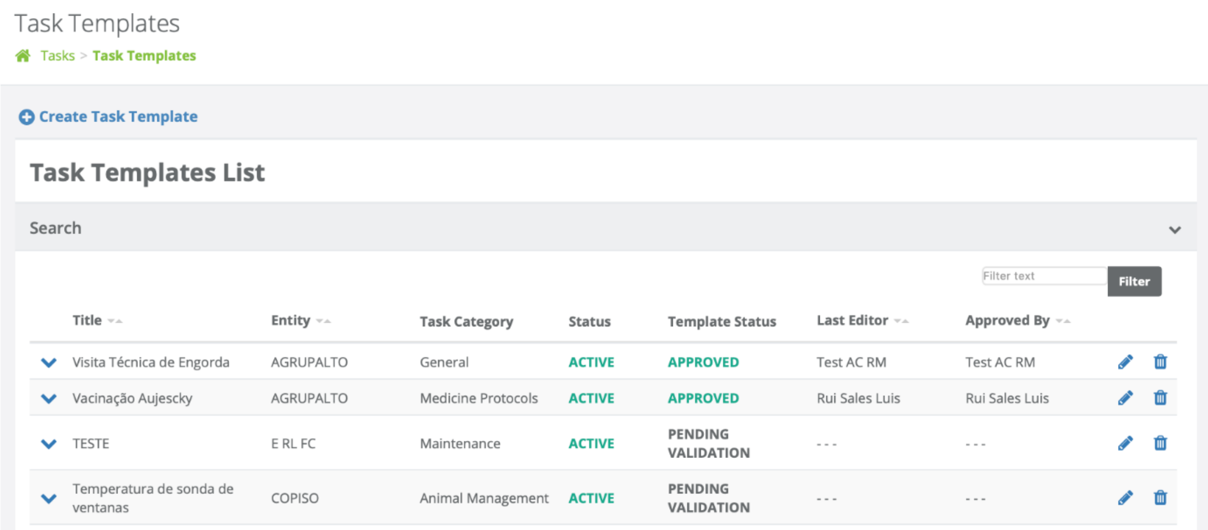


Figure 86 – Task Templates List (UC#7)

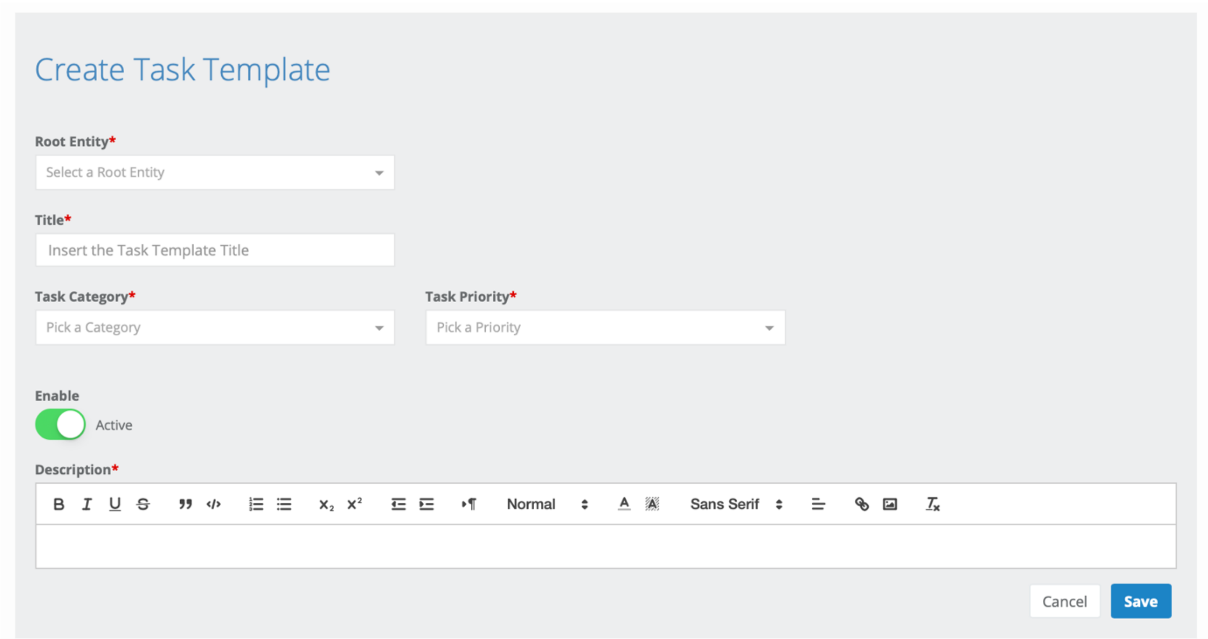


Figure 87 – Create Task Template Screen (UC#7)

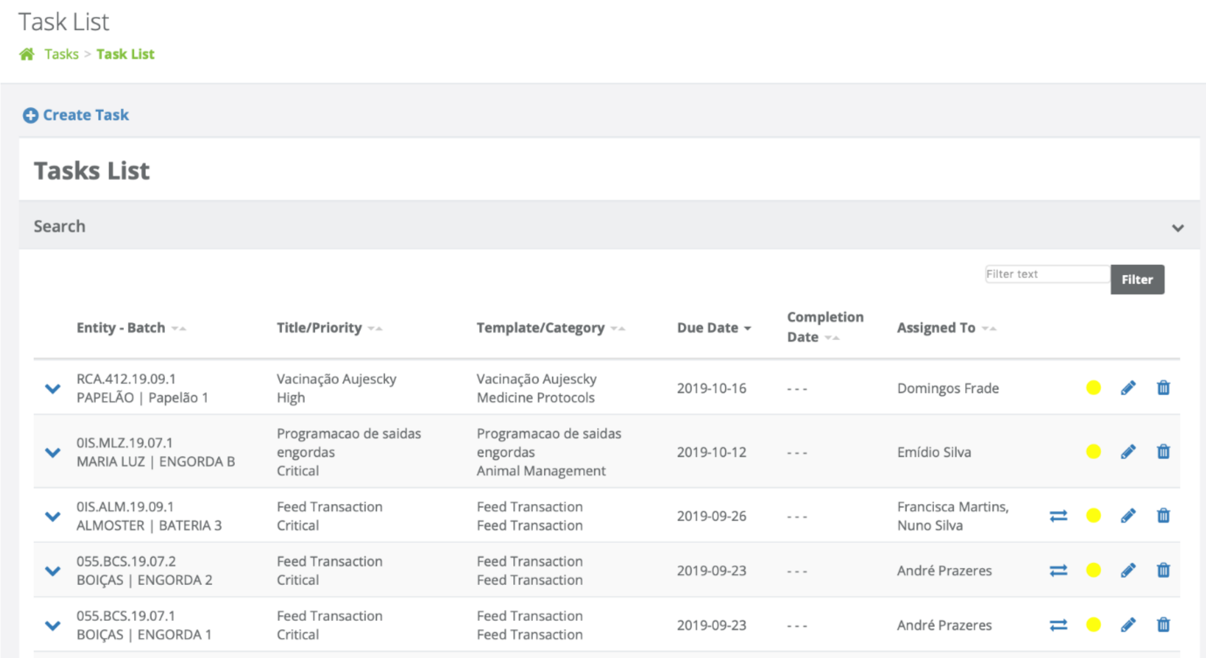


Figure 88 – Tasks List (UC#15)

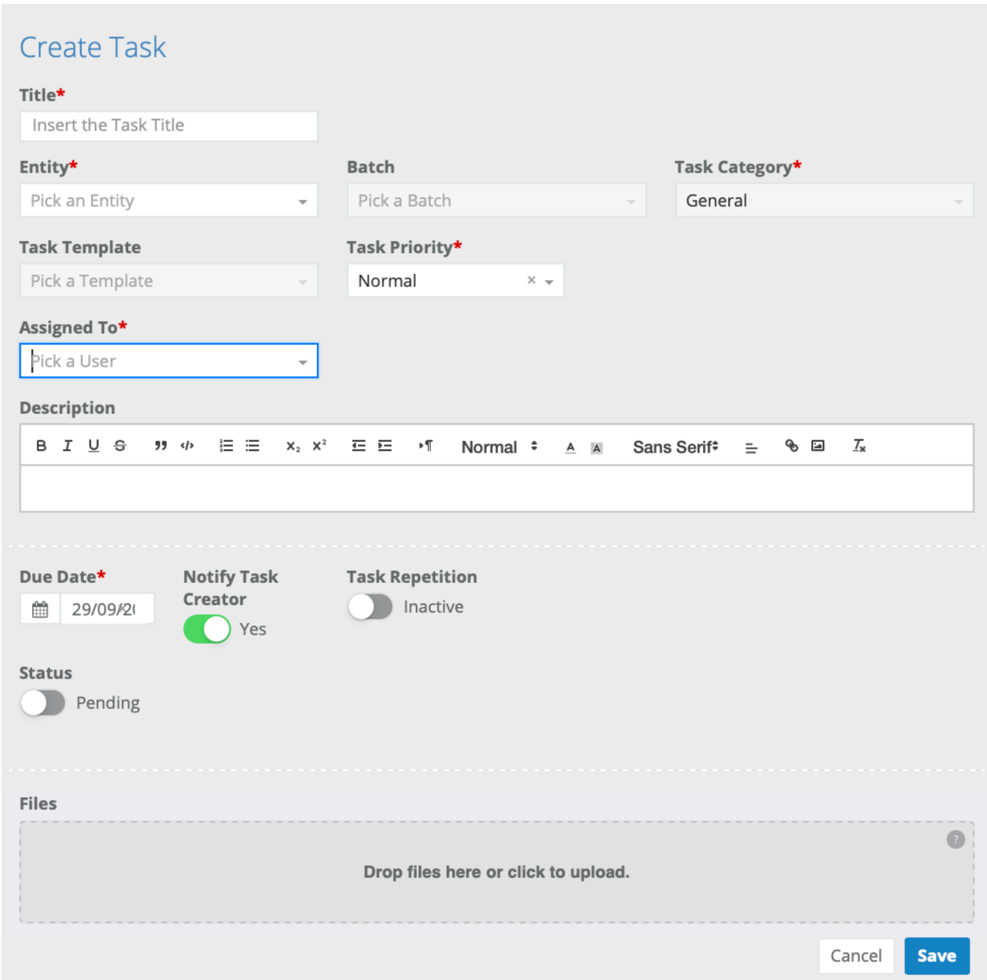


Figure 89 – Create Task Screen (UC#15)

Dashboards

Users already had common IoT dashboards (known in the software as the “Farmview” feature). The new production module provides new data widgets with the new production records data.

Figure 90 – Production Widgets Selection Screen (UC#19/UC#20/UC#21)

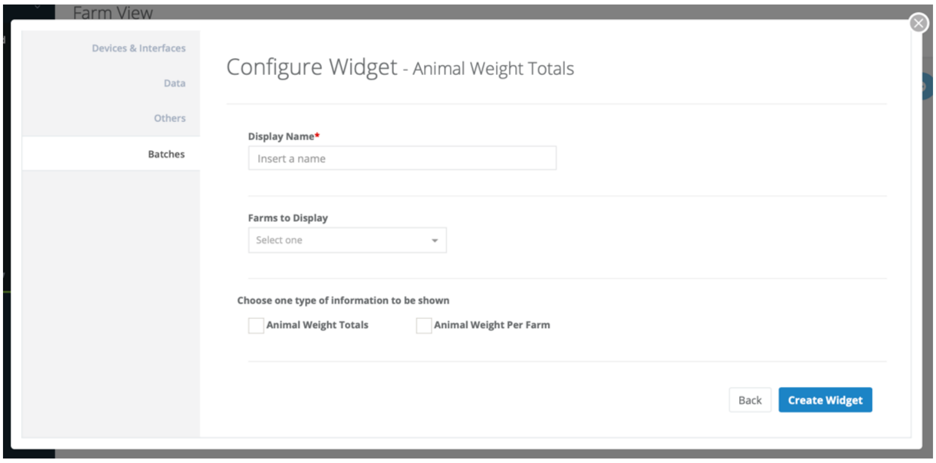


Figure 91 – Animal Weight Widget configuration screen (UC#21)

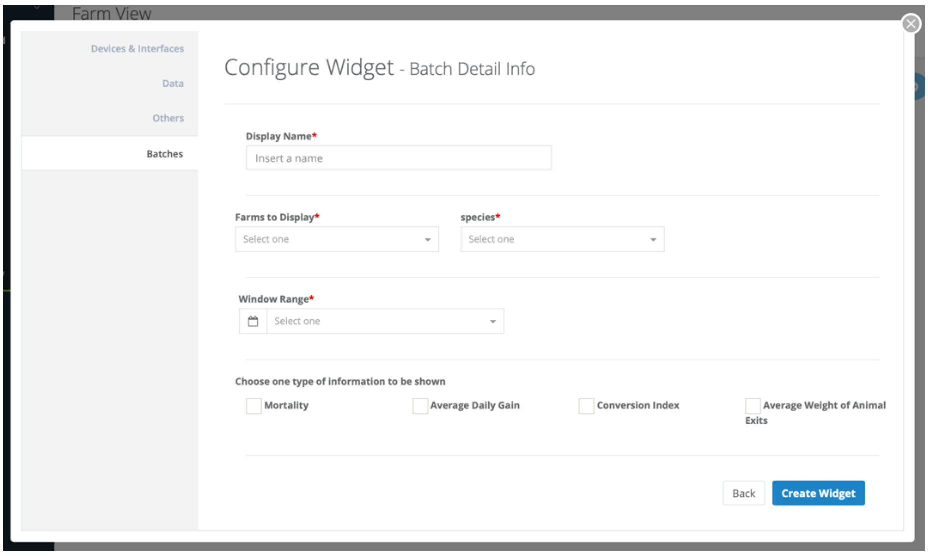


Figure 92 – Batch Detail Info configuration screen (UC#19)

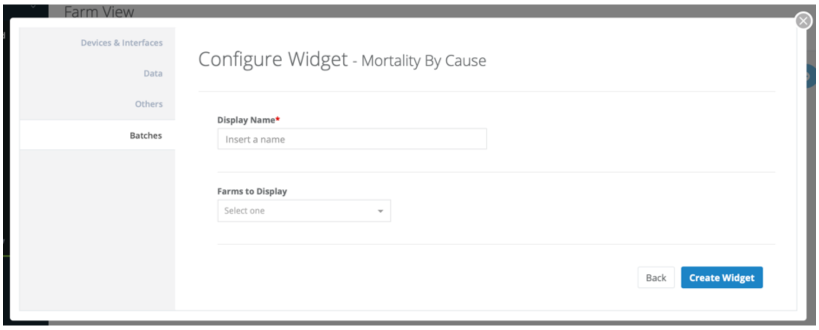


Figure 93 – Mortality Causes widget configuration screen (UC#20)

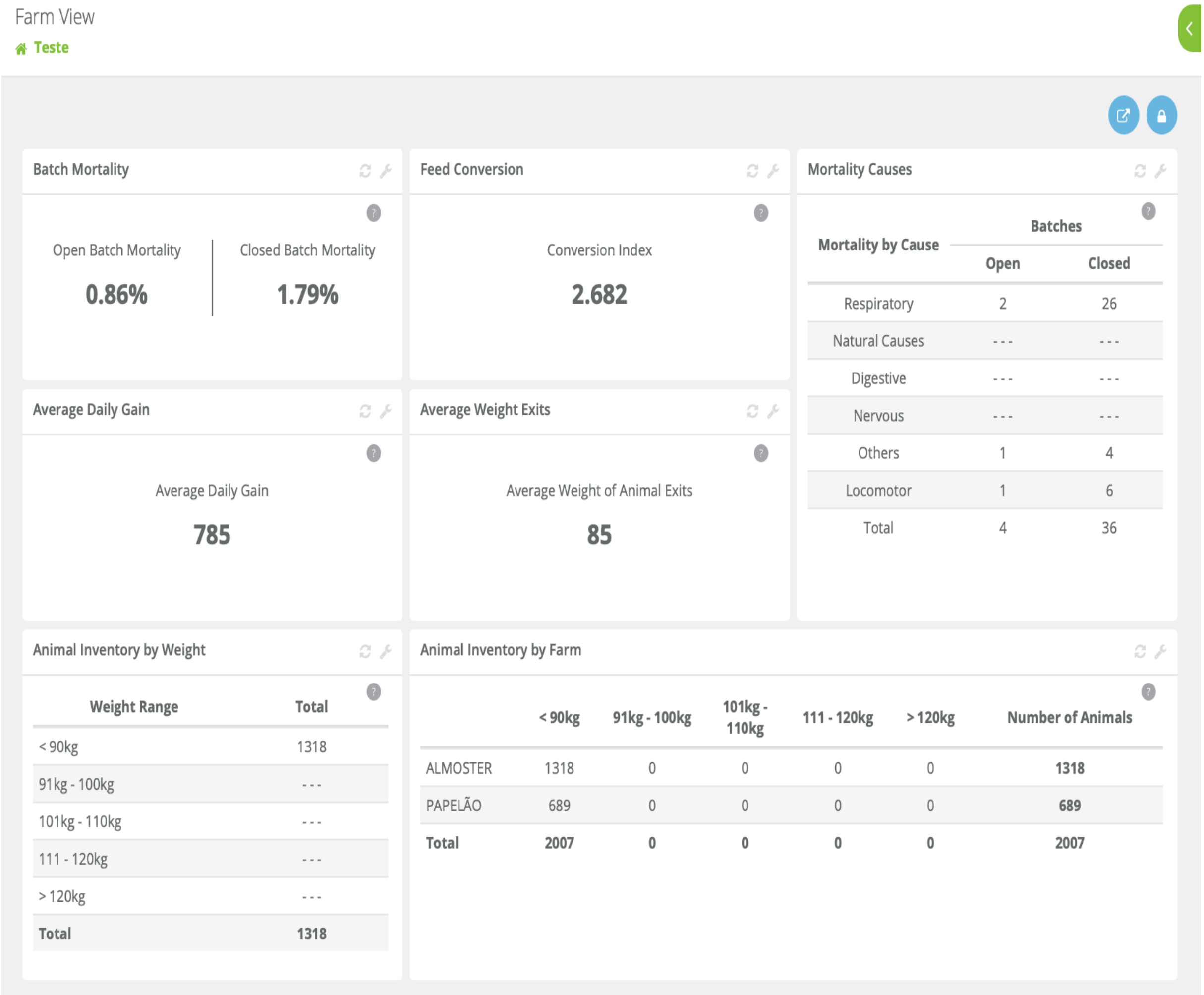


Figure 94 – Sample Production Widgets Dashboard (UC#19/UC#20/UC#21)

4.4.6. Software Outputs

Task Template printed version

Task Template Report
Unloading Animals

Generated By Farmcontrol Report System @ 13-02-2019 [Version 1.0]

Title	**Unloading Animals**	Approved By	**Rúben Madeira**
Category	**Animal Management**	Priority	**High**
Review Comment	**Improves administrative support systems**	Approved On	**2018-11-05**

Description

Initial Checks for Loading and Unloading

- Clear the loading bay and raceway of any obstructions and distractions, e.g. hoses, brushes etc.
- Ensure the raceway leading to/from the loading bay provides a clear and obvious path for the pigs to follow and does not include any right-angled bends.
- Check that the loading bay being used is suitable for the vehicle, i.e. the height of the loading bay and lorry are similar so the ramp is level when dropped.

The external ramp should never be more than 25º and internal ramps should never be more than 33º.

- Secure the loading bay, gates and raceway so that the pigs cannot escape.
- The sides of the raceway should be solid to prevent encourage the pigs forward and minimise distractions.
- Ensure that the floor is clean and, as far as possible, non-slip – use sand if surface is slippery.
- Check how many pigs are being loaded/unloaded, is there enough holding space available for them when they arrive or on the lorry.
- Ensure all paperwork is prepared and completed appropriately.
- Ensure that all the pigs are fit for transport. Arrange separate pen in case any casualty pigs arrive.

Outline of the work: Unloading

- Ensure that the unloading bay is secure and provides a clear way forward for the animals.
- Ensure everybody knows where the animals are going and open/close gates accordingly.
- Keep the slope of the ramp/tailboard to a minimum.
- Allow the pigs to move at their own pace – rushing them will lead to injury.
- Unless they are behind the pigs, keep all people out of the way.
- Monitor the animals and check for any injury or sign of illness that requires attention.
- Secure the pigs in their pens.
- Mixing of pigs from different groups should be avoided wherever possible.
- Complete all relevant paperwork.
- Clean and disinfect the loading bay and raceway once the lorry has left to maintain biosecurity.

Figure 95 – Task Template Printable Version

Production Batch Report

Farmcontrol
PRECISION LIVESTOCK FARMING

Production Batch Report
005.18.08.0

Generated By Farmcontrol Report System @ 13-02-2019 [Version 1.0]

Production Batch Code	**005.18.08.0**	Species	**Industrial Swine | Fattening**
Farm	**Swine Fattening | Demo Farmcontrol**	Control Type	**Growth | All-in / All-out**
Start/End Date	**4/18/2018 - 8/16/2018**	Production Curve	**Suinos - IS Guarita**

Animals In	**560 | 10780 Kgs (19.25 Kgs) - 7 weeks - 5 days**
Animals Out	**551 | 60730 Kgs (110.22 Kgs) - 23 weeks - 3 days**
Feed Per Animal/Total	**218 Kgs | 120080 Kgs**
Days Outside Feeding Prog	**8**

	IC	GMD(g)	%M	PI
Production Curve KPI	**2.40**	**800**	**2.00**	**326.67**
Production Batch KPI	2.40 0% --	809 1% ↑ --	1.61 -19% ↓ --	331.28 % ↑ --
Previous Batch KPI	---	---	---	---

Observations:

Fattening

Animal Movements:

Date	Age	Moviment Type	Doc	Origin/Destiny	Death Cause	N.º Ani.	Weight (kg)	Observations
19-04-2018	53	External Entry	GE22442	V. Henriques		210 ↑	3,960 (18.9)	Chegada Tardia
16-08-2018	170	External Sale	GE23061	Valsabor		148 ↓	17,360 (117.3)	Jejum ok
22-04-2018	54	Death			Others	1 ↓	19 (19.0)	
27-04-2018	59	Death			Respiratory	2 ↓	50 (25.0)	
09-07-2018	132	Death			Digestive	3 ↓	90 (30.0)	
20-07-2018	143	Death			Nervous	1 ↓	30 (30.0)	
22-04-2018	54	Transfarency	GE22174			350 ↑	6,820 (19.5)	GE22174
05-08-2018	159	External Sale	GE23059	Sicasal		75 ↓	8,040 (107.2)	Jejum OK
07-08-2018	161	Death			Coxou	1 ↓	40 (40.0)	
11-08-2018	165	External Sale	GE23060	Raporal		249 ↓	27,360 (109.9)	Jejum OK
16-08-2018	170	Death			Others	1 ↓	45 (45.0)	Abatido
29-07-2018	152	External Sale		Lindarosa		79 ↓	7,970 (100.9)	
					Entries	*560*	*10,780 (19.25)*	
					Exits	*551*	*60,730 (110.22)*	
					Production	*0*	*49,950 (90.65)*	

Figure 96 – Sample Batch Report – Page 1

Farmcontrol
PRECISION LIVESTOCK FARMING

Production Batch Report
005.18.08.0

Feed Movements:

	Type	Doc	Origin/Destination	Input	Quantity (Kg)		Observations
2018-04-19	Buy	G1098	Saprogal	AGP A	4,160	↑	G1098
2018-04-21	Buy	G1252	Saprogal	AGP A	3,860	↑	G1252
2018-04-26	Buy	G1428	Saprogal	AGP A	6,100	↑	G1428
2018-05-03	Buy	G1752	Saprogal	AGP A	4,040	↑	G1752
2018-05-13	Buy	G2252	Saprogal	AGP B	4,180	↑	G2252
2018-05-17	Buy	G2440	Saprogal	AGP B	4,240	↑	G2440
2018-05-23	Buy	G2761	Saprogal	AGP B	4,120	↑	G2761
2018-05-26	Buy	G2942	Saprogal	AGP B	8,180	↑	G2942
2018-06-05	Buy	G3401	Saprogal	AGP B	8,040	↑	G3401
2018-06-12	Buy	G3740	Saprogal	AGP B	4,080	↑	G3740
2018-06-15	Buy	G3943	Saprogal	AGP B	4,020	↑	G3943
2018-06-19	Buy	G4102	Saprogal	AGP B	12,260	↑	G4102
2018-06-27	Buy	G4516	Saprogal	AGP C	8,160	↑	G4516
2018-07-04	Buy	G4911	Saprogal	AGP C	8,040	↑	G4911
2018-07-07	Buy	G5168	Saprogal	AGP C	8,100	↑	G5168
2018-07-17	Transfer	GT796	Demo Farmcontrol | 005.18.08.1	AGP C	400	↓	GT796
2018-07-17	Buy	G5517	Saprogal	AGP C	7,960	↑	G5517
2018-07-21	Buy	G5832	Saprogal	AGP C	8,000	↑	G5832
2018-07-24	Buy	G5902	Saprogal	AGP C	3,240	↑	G5902
2018-07-28	Buy	G6209	Saprogal	AGP C	7,080	↑	G6209
2018-08-01	Buy	G6310	Saprogal	AGP C	6,220	↑	G6310
2018-08-16	Transfer	GT208	Demo Farmcontrol | 005.18.08.2	AGP C	3,600	↓	GT208
				Kgs Consumed	*120,080 kgs*		

Events/Tasks History:

Type	Creation Date	Close Date	Title	Category	Severity	Closing Reason	Created By	Closed By
Task	17-08-2018	13-08-2018	Starting Sector Hygienization	Animal Management	Critical	--	Rúben Madeira	Rúben Madeira
Task	16-08-2018	07-07-2018	Feed Delivery	Ração	Normal	--	Rúben Madeira	Rúben Madeira
Event	16-08-2018	--	Technical visit	Animal Condition	Moderate	Not Relevant	Rúben Madeira	Auto Closed
			Apparently fattening without issues					
Event	16-08-2018	--	Technical visit	Animal Condition	Moderate	Not Relevant	Rúben Madeira	Auto Closed
			Good fattening development					
Event	16-08-2018	--	Technical visit	Animal Condition	Moderate	Not Relevant	Rúben Madeira	Auto Closed
			Good appearance and fattening start					
Event	16-08-2018	--	Technical visit	Climate	Major	Abnormal Climate Conditions	Rúben Madeira	Auto Closed
			Good appearance but temperature of fattening at 31ºC					

Figure 97 – Sample Batch Report – Page 2

Farmcontrol
PRECISION LIVESTOCK FARMING

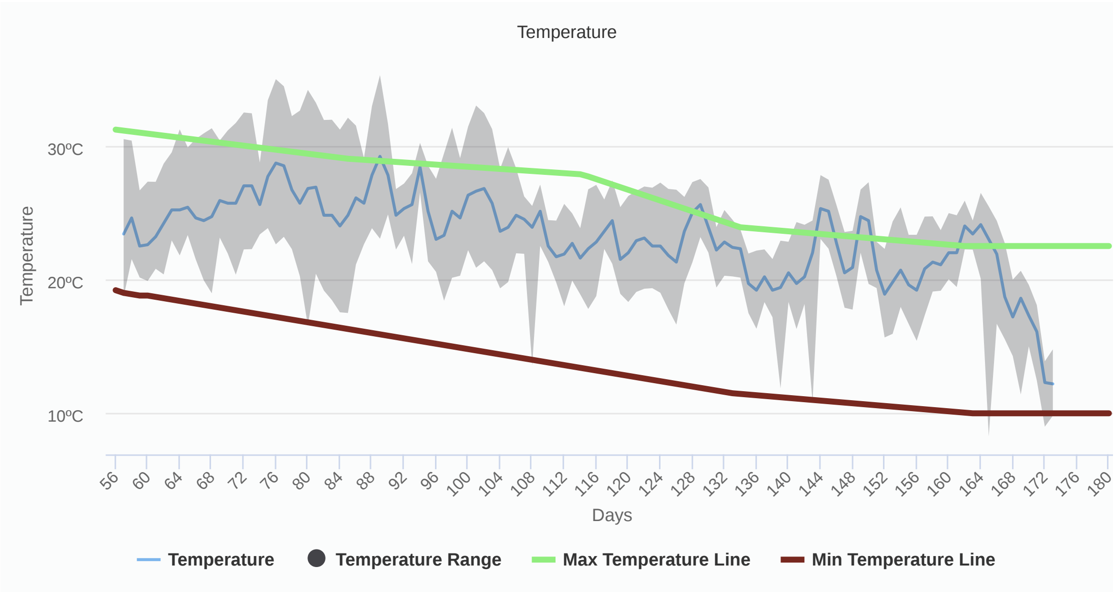
Production Batch Report
005.18.08.0

Type	Creation Date	Close Date	Title	Category	Severity	Closing Reason	Created By	Closed By
Event	16-08-2018	16-08-2018	Evaluation of Animals	Animal Condition	Major	Not Relevant	Rúben Madeira	Rúben Madeira
			Nice aspect of the piglets on arrival although some weaker. 1 hernia of L. Ferro					
Event	16-08-2018	--	Technical visit	Animal Condition	Moderate	error translateEnum	Rúben Madeira	
			Fattening allowed to start sales					
Event	16-08-2018	30-11-2018	Technical visit	Animal Condition	Major	Health Issues	Rúben Madeira	Rúben Madeira
			Some cough but good fattening developement. Recommended Medication.					
Event	16-08-2018	--	Needle Break	Needle break	Critical	Incorrect Procedure	Rúben Madeira	Auto Closed
			Needle Break Incorrect Procedure					
Task	17-08-2018	30-07-2018	Animal Loading	Protocolo Cargas	Normal	--	Rúben Madeira	José Madureira
Task	18-04-2018	--	Starting Sector Hygienization	Animal Management	Critical	--		
Event	16-08-2018	--	Technical visit	Animal Condition	Moderate	Not Relevant	Rúben Madeira	Auto Closed
			Some temperature issues, but good fattening development					
Task	17-08-2018	04-08-2018	Feed Delivery	Ração	Normal	--	Rúben Madeira	Rúben Madeira
Task	16-08-2018	--	Feed Delivery	Ração	Normal	--	Rúben Madeira	
Task	16-08-2018	12-06-2018	Med. Feed Medium Fattening Pigs	Animal Management	Critical	--	Rúben Madeira	Rúben Madeira
Task	16-08-2018	22-04-2018	Animal Unloading	Protocolo Cargas	Normal	--	Rúben Madeira	Rúben Madeira
Task	17-08-2018	16-07-2018	Feed Delivery	Ração	Normal	--	Rúben Madeira	Rúben Madeira
Task	16-08-2018	24-04-2018	Medicate Starter Fattening Pigs	Animal Management	Critical	--	Rúben Madeira	Rúben Madeira
Task	16-08-2018	16-05-2018	Feed changing AGPA->AGPB	Animal Management	Critical	--	Rúben Madeira	Rúben Madeira
Task	16-08-2018	28-06-2018	Feed changing AGPB->AGPC	Animal Management	Critical	--	Rúben Madeira	Rúben Madeira
Task	17-08-2018	22-07-2018	Animal Sale Programing	Animal Management	Critical	--	Rúben Madeira	Rúben Madeira
Task	16-08-2018	29-04-2018	Feed Delivery	Ração	Normal	--	Rúben Madeira	Rúben Madeira
Task	16-08-2018	29-04-2018	Feed Delivery	Ração	Normal	--	Rúben Madeira	Rúben Madeira
Task	17-08-2018	14-07-2018	Fattening Medication	Medicine Protocols		--	Rúben Madeira	Rúben Madeira

Figure 98 – Sample Batch Report – Page 3

Production Batch Report
005.18.08.0

Batch Charts:



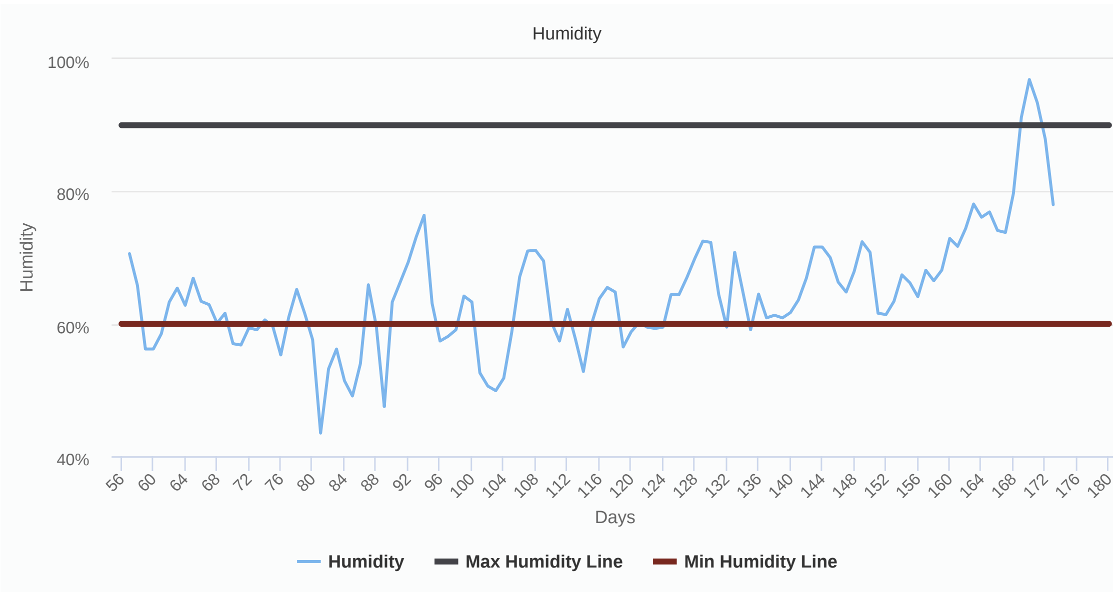
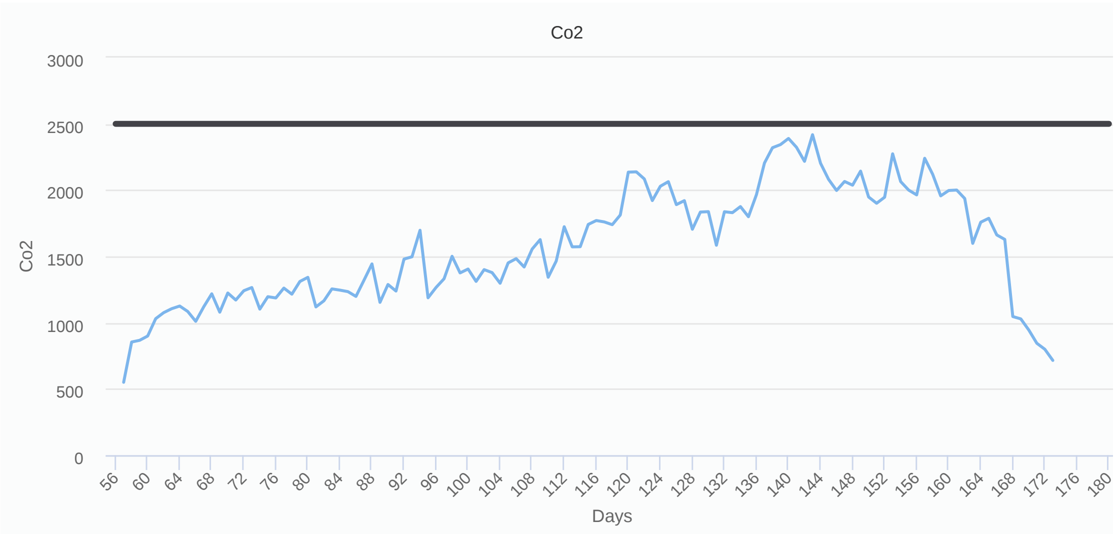


Figure 99 – Sample Batch Report – Page 4

Production Batch Report
005.18.08.0



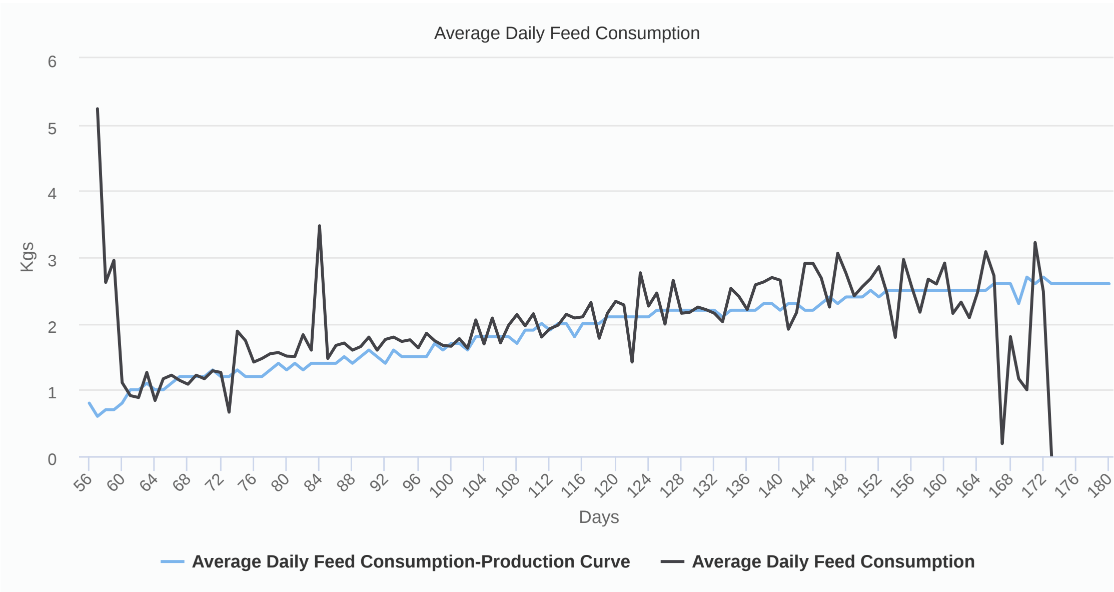


Figure 100 – Sample Batch Report – Page 5

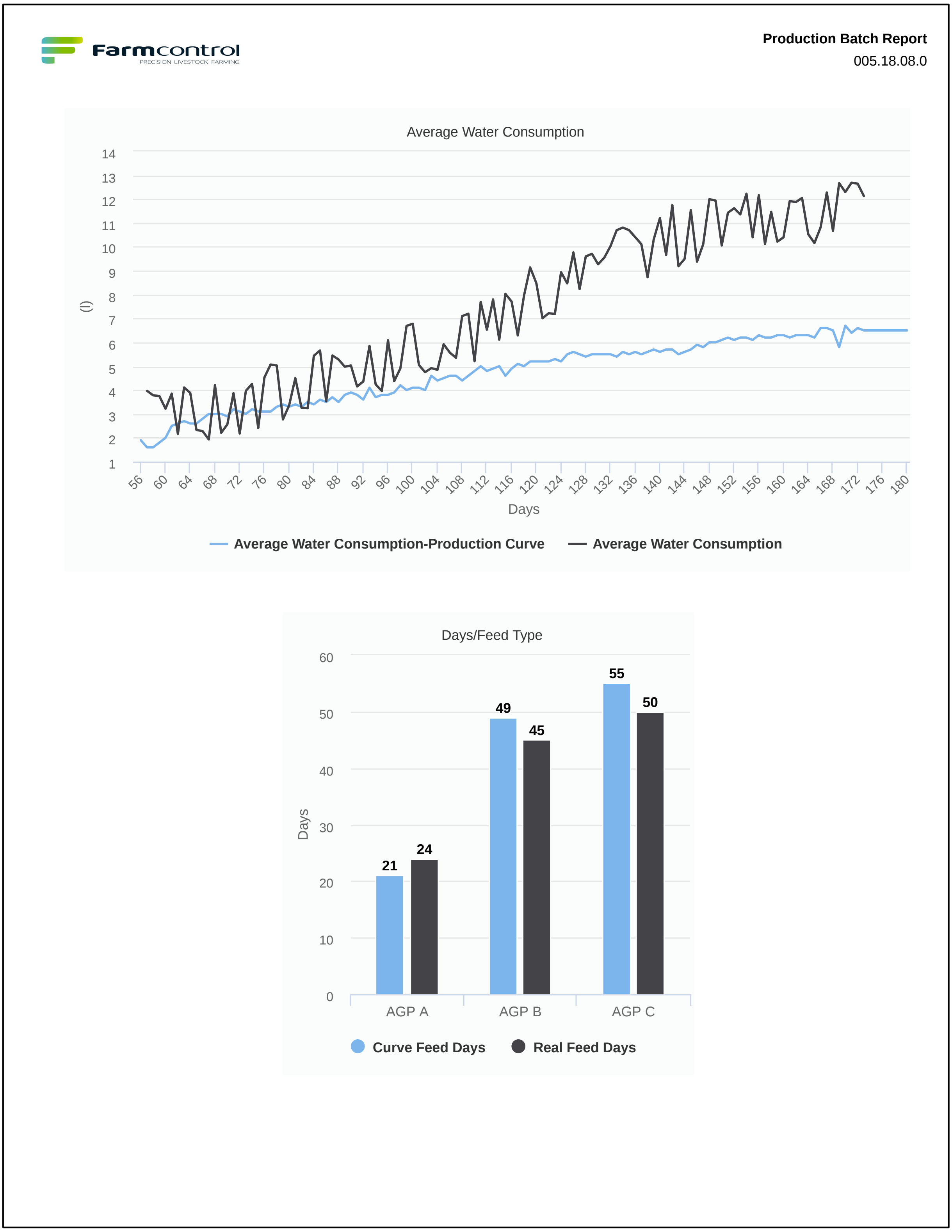


Figure 101 – Sample Batch Report – Page 6

5. PROJECT IMPLEMENTATION & DEPLOYMENT

The software development process took 4 months, 6 sprints and a team of 5 persons, including 3 contracted software developers. The first production-ready version of the software was deployed in May 2019.

The following table summarizes project schedule and deliverables:

			2018								2019											
Stage	Activities	Deliverables	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Preliminary Project Evaluation with Company Management / Elaboration of Master Proposal	Project Definition and Master Proposal	■	■																		
2	Preparing the Project Team	Project Team Nomination and Guidelines		■	■																	
3	Literature Review and Theorethical Framework of the Project	Literature Review, Bibliography Update		■	■	■	■															
	Definition of Technical Requirements	Technical Specifications Document						■	■													
	Implementation Budget and timeline preparation and review	Budget Proposal, Review and Approval								■												
4	Software Development Process	Scrum Reports									■	■	■	■								
5	Product Launch	New Product Marketing Strategy													■							
6	Project Review and guideline for future developments	Project Review Report and Discussion														■	■					
7	Final Master Project Review and Delivery	Final Master Project																■	■	■	■	

Table 18 – Project Schedule

6. PROJECT REVIEW AND EVALUATION

6.1. PROJECT RESULTS AND CLIENT FEEDBACK

Farmcontrol selected three strategic clients that collaborated by deploying the product in real working conditions on farms. Each client selected 3 power users and a workgroup was formed to monitor software implementation in real-world conditions. The workgroup met every two weeks. The agenda of these meetings was to teach the new features to the users, evaluate past problems and get updates on problems/bugs solved by the Dev Team. In these meetings, some software features were refined to be closer to the needs defined by the workgroup. This methodology was a success in terms of tuning the software according to final user needs. It was an opportunity to motivate these reference users to apply the new features to extract the best value of everyday livestock farm work. Final remarks made by the workgroup were very positive, and all members found that the software update was an invaluable tool to reconcile manual farm records with sensor data, allowing them to better understand what is happening in real time and what corrective actions to take. On another note, the software allowed a better communication and collaboration between counselling veterinaries and farm-level workers.

6.2. PROJECT LIMITATIONS AND FUTURE ROADMAP

This work and the implemented solution have some limitations. Most of them derive from the fact that work scope and time frame did not allow the development of all possible features. Nevertheless, this work created a solid basis for further enhancements. Although predictive or descriptive analytics can be used in Precision Livestock Farming tools, this software development focused just on a descriptive analytics tool. A robust database was formed to allow further data exploration and the appliance of new algorithms or data reports that can exponentiate the value retrieved from the software. This work focused on intensive livestock production systems although most principles can be applied to extensive production systems. Individual animal level was not considered (just group level) and animal behaviour sensors were not used. However, they can easily be integrated in the future through the software's API. This work did not dwell much on the hardware aspects of the Farmcontrol solution, because the work goal was to deploy a software-only analytics functionality that integrated an already deployed IoT solution. Regarding the selection of relevant production variables, there is room to improve by adding feed composition detailed data, broader environmental impact evaluation and post farm data from transportation and slaughter. The cost/economic factors considered by some livestock production data analysis and algorithms were considered to be out of scope of this work.

7. CONCLUSIONS

The new production module provides a systematic approach to animal welfare and natural resources efficiency by analysing sensor data in the context of farm and animal characteristics. The farmers can also easily benchmark their livestock production batches in real time, providing instant improvements on critical KPIs, such as feed and water consumption or animal mortality, resulting in a faster ROI. Farm workers can also benefit from these digital tools, because they provide better work efficiency and more time for social life. Farmers – especially younger generations – also experience an increased pride in using digital tools that provide value and also improve consumer trust on livestock activities. The new module was also designed to be attractive to users and lead them to use the software more and also automate early warning alarms if they are not using the software directly as often.

The task and event management tool provides a structured approach to collaboration between farm workers and farm counsellors, such as veterinaries that make regular visits. Tasks can be better perceived, regular procedures can access an instant digital repository, and statistics for the most common problems can help provide better diagnostics and better implementation of recommendations to farmers.

The approach to production batch traceability and the connection to IoT sensors will certainly provide trust across the production chain and differentiate and value the productions that provide this kind of enriched information.

Although technology is not able to replace the farmer, the Farmcontrol production module provides farmers with tools to extract relevant information in real time in a robust and consistent way across the year, instead of photographic, complicated excel-based data analysis that fails to produce permanent change on livestock work procedures. Software implementation on clients will require a strong involvement of the top managers and a skilled farm livestock team that accepts the change in daily business processes and is willingly to get the most value out of a digital transformation project. Solid education of users is also needed. Farmcontrol provides this with the custom “farmcare” support services.

This project was critical for Farmcontrol, because it was a way to differentiate its software solution from the common IoT cloud platforms that are widely available on the market. Now, Farmcontrol can provide more value to livestock farmers and also pave the way for future innovative data exploration.

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ANNEX I - USE CASES FUNCTIONALITIES DESCRIPTION

Use Case	**UC#1 Edit Entities to add production features**
Trigger	User clicks on the edit button on the desired entity screen
Precondition	User is in System/Entities Menu
Basic Path	1. User selects "Farm Code" field and inserts 3 alphanumeric digits as desired 2. User selects "Entity Tags" field and selects the desired tags on the drop-down menu 3. User selects "Usable Area" field and inputs the area available for the animals 4. User clicks on the "Default Interfaces" tab and selects default sensors for Water, Temperature, CO2, Feed Silo Weight, Humidity and Animal Weight on each respective field 5. User clicks on the "Save Entity" button to save changes or "Cancel" button to ignore them
Alternative Paths	• On path 2, the user can create his own customized Tags (described on a separate functionality) • On path 4, the user can add other interface(sensor) categories if needed
Postcondition	Data is updated in the database (DB), user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the "Cancel" button
Other	A Sensor Interface must be available on the respective farm in order to select it

Table 19 – UC#1 Edit Entities to add production features

Use Case	**UC#2 Create Farm Tag**
Trigger	User clicks on the “Create new Tag” button
Precondition	User is on the “Entity” edit screen
Basic Path	1. User inputs new tag name 2. User clicks on the “Create Tag” button
Postcondition	Data is updated in the DB, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the “Cancel” button

Table 20 – UC#2 Create Farm Tag

Use Case	**UC#3 Create/Edit Animal Genetics**
Trigger	User clicks on the “Create Genetics” or “Edit” button on the desired genetic
Precondition	User is on the Genetics List screen in the Production/Genetics menu
Basic Path	1. User selects “Root Entity”, the parent entity where the genetic will be available 2. User inputs name of genetic 3. User selects corresponding animal species 4. User selects or changes Active Status of genetics 5. Optionally, the user can add personal notes in the “Notes” field 6. User clicks on the “Save Genetics” button to save changes or “Cancel” button to ignore them
Postcondition	Data is updated in the DB, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the “Cancel” button
Other	If the Genetic Status is Inactive, it will not be available for selection on other parts of the software

Table 21 – UC#3 Create/Edit Animal Genetics

Use Case	**UC#4 Create/Edit Animal Death Reasons**
Trigger	User clicks on the "Create Death Reason" or "Edit" button on the desired death reason
Precondition	User is on the Death Reasons List screen in the Production/Death Reasons menu
Basic Path	1. User selects the "Root Entity", the parent entity where the death reason will be available 2. User inputs name of death reason 3. User selects Death Reason Category from drop down menu (system) 4. User selects corresponding animal species from drop down menu 5. User selects or changes Active Status 6. User clicks on "Save" button to save changes or "Cancel" to ignore them
Postcondition	Data is updated in the DB, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the "Cancel" button
Other	If the Death Reason Status is Inactive, it will not be available for selection on other parts of the software

Table 22 – UC#4 Create/Edit Animal Death Reasons

Use Case	**UC#5 Create/Edit Feed Types**
Trigger	User clicks on the "Create Feed Type" or "Edit" button on the desired feed type
Precondition	User is on the Feed Types List screen in the Production/Feed Types menu
Basic Path	1. User selects Root Entity, parent entity where the feed type will be available 2. User inputs name of Feed Type 3. User selects or changes Active Status 4. User inputs External Identifier field 5. User clicks on the "Save" button to save or "Cancel" button to ignore them
Postcondition	Data is updated in the DB, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the "Cancel" button
Other	• If the Feed Type Status is Inactive, it will not be available for selection on other parts of the software • The "External Identifier" field is used to interface with other software

Table 23 – UC#5 Create/Edit Feed Types

Use Case	**UC#6 Create/Edit Feed Factories**
Trigger	User clicks on the "Create Feed Factory" or "Edit" button on the desired feed Factory
Precondition	User is on the Feed Factories List screen in the Production/Feed Factories menu
Basic Path	1. User selects "Root Entity", the parent entity where the feed Factory will be available 2. User inputs name of Feed Factory 3. User selects or changes Active Status 4. User inputs External Identifier field 5. User clicks on "Save" button to save changes or "Cancel" to ignore them
Postcondition	Data is updated in the db, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the "Cancel" button
Other	• If the Feed Factory Status is Inactive, it will not be available for selection on other parts of the software • The "External Identifier" field is used to interface with other software

Table 24 – UC#6 Create/Edit Feed Factories

Use Case	**UC#7 Create/Edit Tasks Templates**
Trigger	User clicks on the "Create Task Template" or "Edit" button
Precondition	User is on the Task Templates list screen in the Tasks/Task Templates menu
Basic Path	1. User selects "Root Entity", the parent entity where the Task Template will be available 2. User inputs Title of Task Template 3. User selects Task Category from drop down menu (system) 4. User selects Task Category Priority from drop down menu (system) 5. User selects or changes Active Status 6. User inputs Task Template description text 7. User clicks on the "Save" button to save changes or "Cancel" button to ignore them
Postcondition	Data is updated in the DB, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the "Cancel" button

Table 25 – UC#7 Create/Edit Tasks Templates

Use Case	UC#8 Create/Edit Production Curves
Trigger	User clicks on the "Create Production Curve" or "Edit" button on the desired feed type
Precondition	User is on the Prod.Curves list screen in the Production/Production Curves menu
Basic Path	1. User selects the "Root Entity", the parent entity where the Production Curve will be available 2. User inputs Display name and Title of Production Curve 3. User selects corresponding animal species from drop down menu 4. User selects Closure Task from drop down menu 5. User selects or changes Active Status 6. User inputs production goals for Feed Conversion, Average Daily Gain, Mortality Rate or Performance Index 7. Optionally, the user can add personal notes in the "Notes" field 8. User clicks on the "Save" button to save changes or "Cancel" to ignore them
Postcondition	Data is updated in the DB, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the "Cancel" button

Table 26 – UC#8 Create/Edit Production Curves

Use Case	UC#9 Import/Export Production Curve Details
Trigger	User clicks on the "Production Curve details" button on the desired production curve
Precondition	User is on the Prod.Curves list screen in the Production/Production Curves menu
Basic Path	Optionally: 1. User clicks on the "Import Data from CSV" button and selects the desired file on the local computer 2. User clicks on the "Export Data to CSV" button
Postcondition	On Import: If data format is correct, Data is updated in the DB, user is shown a confirmation screen; otherwise data is rejected, and user is given an error screen On Export: An exported CSV format file is downloaded and saved in the default local download folder of the browser that is being used

Table 27 – UC#9 Import/Export Production Curve Details

Use Case	UC#10 Create/Edit Production Batches
Trigger	User clicks on the "Create Batch" or "Edit" button on the desired prod.batch
Precondition	User is on the Batches list screen in the Production/Batches menu
Basic Path	1. User selects "Enterprise", "Farm" and "Sector" where the production batch will take place 2. User selects corresponding animal species from drop down menu 3. User selects corresponding animal genetics from drop down menu 4. User selects production flow from drop down menu (system) 5. User selects production curve from drop down menu 6. User inputs batch open date (current date is suggested) 7. User optionally inputs "Class" field 8. User optionally inputs personal observations in the "Observations" field 9. User can add an external file by dragging and dropping the desired file to Files field "drop zone" 10. User clicks on the "Save" button to save changes or "Cancel" to ignore them
Postcondition	Data is updated in the DB, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the "Cancel" button
Other	The "Class" field is used to interface with other software

Table 28 – UC#10 Create/Edit Production Batches

Use Case	**UC#11 View Batch Information**
Trigger	User clicks on the "Batch Details" on the desired prod.batch
Precondition	User is on the Batches list screen in the Production/Batches menu
Basic Path	1. User consults basic batch information on the top of the screen (always available), "Totals" tab is the default displayed tab 2. Optionally, the user can cycle through available tabs to see desired information: Totals, Animal Movements, Feed Movements, Events, Tasks, Weighting, and Batch View 3. There is a shortcut to create or edit each type of data displayed on each tab 4. User can optionally interact with graph charts in the "Batch View" menu
Postcondition	Just the display of data on screen as required
Exception Paths	User can go back to previous menu when needed by pressing the "Batches" menu shortcut
Other	Graph Charts on "Batch View" tab are only displayed if "default interfaces" of sensors are correctly assigned to farm sector entity

Table 29 – UC#11 View Batch Information

Use Case	**UC#12 Create/Edit Production Batch Animal Transaction**
Trigger	User clicks on the "Create Transaction" button or "Edit" button on the desired transaction
Precondition	User is on Batch Details page on the Animal Movements Tab

Basic Path	1. User inserts transaction date and time
	2. User selects type of action using corresponding "External Entry", "External Sale", "Transfer", "Death" buttons
	    a. "Origin" and "Age" fields must be input if "External Entry" is selected
	    b. "Destination" field must be input if "External Sale" is selected
	    c. Destination Batch must be selected if "Transfer" is selected
	    d. "Cause of Death" field must be input if "Death" is selected
	3. User inputs Number of Animals and Total Weight fields
	4. User inputs external document number (optional)
	5. User inputs Observations (optional)
	6. User adds external file (optional)
	7. User clicks on the "Save" button to save changes or "Cancel" button to ignore them

Alternative Paths	• User can go to Production/Animal Movements menu and create the transaction there • User can press top bar shortcut to create transaction
Postcondition	Data is updated in the DB, user is shown a confirmation screen
Exception Paths	User can cancel at any time by pressing the "Cancel" button

Table 30 – UC#12 Create/Edit Production Batch Animal Transaction

Use Case	**UC#13 Create/Edit Production Batch Feed Transaction**
Trigger	User clicks on the "Create Feed Transaction" button or "Edit" button on the desired transaction
Precondition	User is on Batch Details page on the Feed Movements Tab
Basic Path	1. User inserts transaction date and time 2. User selects type of action in corresponding buttons of "Transfer" or "Buy" a. "Farm" and "Batch" fields must be selected when "Transfer" is selected b. "Feed Factory" and "Notify Yes/No" fields must be selected when "Buy" is selected 3. User inputs Total Weight of feed field 4. User inputs external document number (optional) 5. User inputs Observations (optional) 6. User adds external file (optional) 7. User clicks on the "Save" button to save changes or "Cancel" button to ignore them
Alternative Paths	• User can go to Production/Feed Movements menu and create the transaction there • User can press top bar shortcut to create transaction
Postcondition	Data is updated in the DB, user is shown a confirmation screen. If transaction date is a future date, transaction is marked as "pending" in the db. If the notification option is selected, the feed factory will receive an e-mail with the feed order.
Exception Paths	User can cancel at any time by pressing the "Cancel" button

Table 31 - UC#13 Create/Edit Production Batch Feed Transaction

Use Case	**UC#14 Create/Edit Production Batch Event**
Trigger	User clicks on the “Create Event” button or “Edit” button on the desired event
Precondition	User is on Batch Details page on the Events Tab
Basic Path	1. User inputs event title 2. User selects required event severity from “Warning”, “Minor”, “Major” or “Critical” 3. User inputs event description 4. User selects event category (system) 5. User inputs event date and time (current date and time are suggested) 6. User selects “Open”, “Pending” or “Closed” status a. The closing reason field must be selected from the drop-down menu (system) when “Closed” status is selected 7. User inputs event notes (optional) 8. User selects other users for notification by e-mail in the “Send Email” drop down field (optional) 9. User selects other users for notification by SMS in the “Send SMS” drop down field (optional) 10. User adds external file (optional) 11. User clicks on the “Create” button to save changes, “Submit and Create” button to immediately save and trigger a new event to input on the same farm and batch, or “Cancel” button to ignore them
Alternative Paths	• User can go to the Events menu and create the event there • User can press top bar shortcut to create event
Postcondition	Data is updated in the DB, user is shown a confirmation screen. If there are users to notify, they will be sent an email or SMS as selected according to event information
Exception Paths	User can cancel at any time by pressing the “Cancel” button

Table 32 – UC#14 Create/Edit Production Batch Event

Use Case	**UC#15 Create/Edit Production Batch Task**
Trigger	User clicks on the “Create Task” button or “Edit” button on the desired task
Precondition	User is on Batch Details page on the Tasks Tab
Basic Path	1. User inputs task title 2. User selects task category (system) 3. User selects task template (optional) 4. User selects task priority from “Normal”, “High” or “Critical” 5. User selects user assigned for the task (current user is suggested) 6. User inputs Description (in case a task template was not selected) 7. User inputs task due date (current date is suggested) 8. User selects the “Notify Task Creator” option 9. User selects the “Task Repetition” option. In case this option was selected, two new fields must be input: a. Repetition time in Days, Weeks or Months b. End of repetition date 10. User selects event status from “Done” or “Pending” a. A completion date must be input (current date is suggested) when “Done” is selected b. Completion notes may be input (optional) when “Done” is selected 11. User adds external file (optional) 12. User clicks on the “Save” button to save changes or “Cancel” button to ignore them
Alternative Paths	• User can go to Tasks menu and create the task there • User can press top bar shortcut to create task
Postcondition	Data is updated in the DB, user is shown a confirmation screen. If the “notify task creator” option is selected, task creator user will be notified upon task completion
Exception Paths	User can cancel at any time by pressing the “Cancel” button

Table 33 – UC#15 Create/Edit Production Batch Task

Use Case	**UC#16 Create/Edit Manual Animal Weightings**
Trigger	User clicks on the “Create Weighting” button or “Edit” button on the record
Precondition	User is on Batch Details page on the Weightings Tab
Basic Path	1. User inserts weighting date and time (current date and time are suggested) 2. User inserts weight and the following average daily gain 3. User inputs Observations (optional) 4. User clicks on the “Save” button to save changes or “back” button to ignore
Alt.Paths	User can press top bar shortcut to create weighting
Postcondition	Data is updated in the DB, user is shown a confirmation screen.
Exception Paths	User can cancel at any time by pressing the “Back” button

Table 34 – UC#16 Create/Edit Manual Animal Weightings

Use Case	**UC#17 Close Production Batch**
Trigger	User clicks on the Production Batch Details “Status” button to close the Batch
Precondition	User is on Batch Details page, and production batch must have zero animals in inventory
Basic Path	User presses Batch Status switch button to close batch
Postcondition	Data is updated in the DB, user is shown a confirmation screen.
Exception Paths	User can go back by pressing the “Status” button again

Table 35 – UC#17 Close Production Batch

Use Case	**UC#18 Print Production Batch Report**
Trigger	User clicks on the Production Batch Details “Download Batch Report” button
Precondition	User is on Batch Details page
Basic Path	User presses “Download Batch Report” button
Postcondition	The system sends current batch report to active user’s e-mail
Alternate Paths	User can produce the report on software “Reports” Menu

Table 36 – UC#18 Print Production Batch Report

Use Case	**UC#19 Create Batch Detail Info Widget**
Trigger	User presses the "Create Widget" button
Precondition	User is on an unlocked dashboard (farmview) screen
Basic Path	1. User selects the "Batches" tab on widget creation screen 2. User clicks on the "Batch Detail Info" button 3. User inputs display name 4. User selects farm(s) to display 5. User selects animal species 6. User selects Window Time Range of the information to be displayed 7. User selects type of information to be displayed by marking the relevant checkboxes: "Mortality", "Average Daily Gain", "Feed Conversion Index", "Average Weight of Animal Exits" 8. User saves information by pressing the "Create Widget" button or cancels by pressing the "Back" button
Postcondition	The dashboard that is current displayed is updated with the new Widget
Exception Paths	User can go back by pressing the "back" button

Table 37 – UC#19 Create Batch Detail Info Widget

Use Case	**UC#20 Create Mortality Cause Widget**
Trigger	User presses the "Create Widget" button
Precondition	User is on an unlocked dashboard (farmview) screen
Basic Path	1. User selects the "Batches" tab on widget creation screen 2. User selects "Mortality by Cause" button 3. User inputs display name 4. User selects farm(s) to display 5. User saves the information by pressing the "Create Widget" button or cancels by pressing the "Back" button
Postcondition	The dashboard that is current displayed is updated with the new Widget
Exception Paths	User can go back by pressing the "back" button

Table 38 – UC#20 Create Mortality Cause Widget

Use Case	**UC#21 Create Animal Weight Widget**
Trigger	User presses the "Create Widget" button
Precondition	User is on an unlocked dashboard (farmview) screen
Basic Path	1. User selects the "Batches" tab on widget creation screen 2. User clicks on the "Animal Weight Totals" button 3. User inputs display name 4. User selects farm(s) to display 5. User selects type of information to be displayed by marking the relevant checkboxes: "Animal Weight Totals", "Animal Weight Per Farm" 6. User saves the information by pressing the "Create Widget" button or cancels by pressing the "Back" button
Postcondition	The dashboard that is current displayed is updated with the new Widget
Exception Paths	User can go back by pressing the "back" button

Table 39 – UC#21 Create Animal Weight Widget

ANNEX II – DESCRIPTION OF DATABASE TABLES

A description of the main database tables is presented that includes information about data types and variable description:

Entities (new fields)			
PK	id	uuid	Unique Identifier
	display name	varchar(255)	Display Name
	name	varchar(255)	Name
	properties	jsonb	Properties
	status	varchar(255)	Status (Active/Inactive)
	farm id	uuid	Unique Farm Identifier
	code	varchar(3)	Batch Number Code
	usable area	float8	Usable area for animals in m^2

Table 40 – Entities (new fields)

Entity tag mapping			
PK	tag id	uuid	Unique Tag Identifier
PK	entity id	uuid	Unique Entity Identifier

Table 41 – Entity tag mapping

Production species			
PK	value	varchar(255)	Species Name
	translations	jsonb	Translations

Table 42 – Production species

Production subspecies			
PK	value	varchar	Subspecies Name
	translations	jsonb	Translations
	species	varchar	Species Name

Table 43 – Production sub species

Production type modes			
PK	value	varchar	Name of Production Type Mode
	translations	jsonb	Translations

Table 44 – Production type modes

Production type sub-modes			
PK	value	varchar	Name of Production Type Sub-mode
	translations	jsonb	Translations

Table 45 – Production type sub-modes

Production types			
PK	id	uuid	Unique Identifier
	mode	varchar	Production Type Mode
	sub mode	varchar	Production Type Sub-Mode
	max balance	integer	Batch Stock Limit (1 if Individual)

Table 46 – Production types

Animal genetics			
PK	id	uuid	Unique Identifier
	display name	varchar	Display Name
	entity id	uuid	Reference to Parent Entity
	sub species	varchar	Reference to Species
	status	bool	Status (Active/Inactive)
	notes	text	General Notes Field

Table 47 - Animal genetics

Species death reason categories			
PK	value	varchar(255)	Category Name
	name	jsonb	Translations
	enable	bool	Status (Active/Inactive)

Table 48 – Species death reason categories

Species death reasons			
PK	id	uuid	Unique Identifier
	display name	varchar	Display Name
	entity id	uuid	Reference to Parent Entity
	sub species	varchar	Reference to Species
	status	bool	Status (Active/Inactive)
	species death reason cate gory	varchar	Reference to Death Category

Table 49 – Species death reasons

Feed types			
PK	id	uuid	Unique Identifier
	display name	varchar	Display Name
	entity id	uuid	Reference to Parent Entity
	status	bool	Status (Active/Inactive)
	external identifier	text	Code for Interface with other Software
	observations	text	General Notes Field

Table 50 – Feed types

Feed factories			
PK	id	uuid	Unique Identifier
	display name	varchar	Display Name
	entity id	uuid	Reference to Parent Entity
	status	bool	Status (Active/Inactive)
	external identifier	text	Code for Interface with other Software
	observations	text	General Notes Field
	email	varchar	Feed Factory e-mail
	phone number	varchar	Feed Factory Phone Number

Table 51 – Feed factories

Production curves			
PK	id	uuid	Unique Identifier
	name	varchar	Name
	display name	varchar	Display Name
	entity	uuid	Reference to Parent Entity
	sub species	varchar	Reference to Species
	status	bool	Status (Active/Inactive)
	notes	text	General Notes Field
	conversion index	float8	Feed Conversion Factor Goal
	average daily gain	float8	Average Daily Weight Gain Goal
	mortality rate	float8	Mortality Rate Goal
	performance index	float8	Performance Index Goal
	closure task template id	uuid	Triggered Closing Task for Batch

Table 52 – Production curves

Production curve details			
PK	id	uuid	Unique Identifier
	age	integer	Age (days)
	feed type	uuid	Feed Type for Age
	allow exit	bool	Recommended Exit for Age (Y/N)
	weight	real	Weight Goal for Age
	average daily feed consu mption	real	Daily Feed Consumption Goal for Age
	average daily water consu mption	real	Average Water Consumption Goal for Age
	max temperature	real	Maximum Comfort Temperature for Age
	min temperature	real	Minimum Comfort Temperature for Age
	max humidity	real	Maximum Comfort Humidity for Age
	min humidity	real	Minimum Comfort Humidity for Age
	max co2	real	Maximum Comfort CO2 for Age
	production curve id	uuid	Reference to Production Curve
	task templates id	uuid	Set Triggered Task for Age

Table 53 – Production curve details

Production batches			
PK	id	uuid	Unique Identifier
	prefix	varchar	Prefix formed by “YY.MM”
	seq	integer	Sequence number inside each month
	entity id	uuid	Farm Entity Id
	production type id	uuid	Production Type
	production curve id	uuid	Production Curve
	status	bool	Status (Active/Inactive)
	sub species	varchar	Reference to Species
	animal genetics id	uuid	Genetics Id
	open date	date	Open Date
	close date	date	Close Date
	external code	varchar	Official Farm Legal Number
	production class	text	Code for Interface with other Software
	observations	text	General Notes Field

Table 54 – Production batches

Production batch animal transactions			
PK	id	uuid	Unique Identifier
	batch id	uuid	Batch Id Key
	inverse transaction id	uuid	Reference to Transfer Origin/Destination
	timestamp utc	timestamp	Date and Time
	action	varchar	Action
	action type	varchar	Action Type (Entry/Exit/Death/Transfer)
	production exit	bool	Signal Production Exits (Y/N)
	type description	varchar	Action Type Description
	death reason id	uuid	Reference to Death Reason
	number	integer	Number of Animals
	weight	real	Weight of Animals
	age	real	Age of Animals
	document	text	Document Number
	observations	text	General Notes Field
	pending	bool	Transaction Confirmed (Y/N)
	completion task id	uuid	Reference to Completion Task

Table 55 – Production batch animal transactions

Production batch feed transactions			
PK	id	uuid	Unique Identifier
	batch id	uuid	Reference to Production Batch
	inverse transaction id	uuid	Reference to Transfer Origin/Destination
	timestamp utc	timestamp	Date and Time
	feed factory id	uuid	Reference to Feed Factory
	action	varchar	Action
	action type	varchar	Action Type (Entry/Transfer)
	medicated	bool	Medicated (Yes/No)
	weight	real	Feed Weight
	document	text	Document Number from supplier
	observations	text	General Notes Field
	tenant id	uuid	Reference to Entity
	feed type id	uuid	Reference to Feed Type
	pending	bool	Transaction Confirmed (Y/N)
	completion task id	uuid	Reference to Completion Task
	notify	bool	Notify Completion (Y/N)

Table 56 – Production batch feed transactions

Production batch manual weighting			
PK	id	uuid	Unique Identifier
Idx	production batch	uuid	Reference to Production Batch
Idx	timestamp utc	timestamp	Date and Time
	weight	numeric	Animal Weight
	weight units	varchar(10)	Weight Unit
	adg	numeric	Set Average Weight Daily Gain
	observations	text	General Notes Field

Table 57 – Production batch manual weighting

Events			
PK	id	uuid	Unique Identifier
	additional notes	text	Additional Notes
	description	text	Event Description
	event date	timestamp	Date
	severity level	varchar(255)	Severity Level (Warning/Minor/Major/Critical)
	status	varchar(255)	Status (Open/Pending/Closed)
	title	varchar(255)	Event Title
	category	varchar(255)	Event Category
	closing reason	varchar(255)	Closing Reason
	entity id	uuid	Reference to Entity
	origin	varchar(255)	Origin (From Rule/Manual)
	batch id	uuid	Reference to Production Batch

Table 58 – Events

Task categories			
PK	value	varchar(255)	Task Category Name
	name	jsonb	Translations
	enable	bool	Active (Y/N)
	system category	bool	System Category (Y/N)

Table 59 – Task categories

Tasks			
PK	id	uuid	Unique Identifier
	title	varchar	Task Title
	description	text	Task Description
	task template id	uuid	Reference to Task Template
	category	varchar	Task Category
	status	bool	Completed (Y/N)
	priority	varchar	Task Priority
	entity id	uuid	Reference to Entity
	batch id	uuid	Reference to Production Batch
	due date	date	Task Due Date
	completion date	date	Task Completion Date
	completion notes	text	General Notes Field
	notify task creator	bool	Notify Task Creator (Y/N)
	task repetition	bool	Task Repetition (Y/N)
	repetition delay	integer	Repetition Delay
	repetition triggered	bool	Triggered Repetition (Y/N)

Table 60 – Tasks

Task templates			
PK	id	uuid	Unique Identifier
	title	varchar	Task Template Title
	description	text	Task Template Description
	entity id	uuid	Reference to Parent Entity
	enable	bool	Approved (Y/N)
	status	varchar	Active (Y/N)
	priority	varchar	Priority
	comment	varchar	General Notes Field
	approved by	uuid	Reference to approval by User
	category	varchar	Task Template Category
	rating	integer	Task Template Rating
	evaluations	integer	Number of rating evaluations

Table 61 – Task templates