Chapter 16

Practical experiences of IoT applications in the IoF2020 Dairy Trial

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Abstract

The goal of the H2020 IoF2020 Large Scale Project (LSP) is to stimulate the uptake of Internet-of-Things (IoT) solutions in the Agri-food sector and is founded on several major trials comprising multiple use cases. A use case, driven by a consortium of (SME) companies, research institutes and end users, defines, develops, tests, validates and showcases IoT solutions in a segment of the overall agri-food domain. One of the major segments is the dairy sector and associated trial comprises seven use cases developing minimal viable products (MVPs) for the dairy farming, evaluated in operational environments across Europe. The evaluation strategy centres not only on confirming the technical performance of the solution, but more importantly demonstrating the value of the solution to the business captured through specific KPI's agreed by the community. Within a large-scale project such as IoF2020, all use cases co-operate and share both technical know-how and developments as well as best practices. The technical developments are supported by business and ecosystem work packages providing expertise, experience and new tools to accelerate the commercialisation of the innovation within each use case. The use cases within the dairy trial are an exemplar where the exchange of know-how and results has benefited each of the developments. The detail of the use cases, their inter-relationships and achievements are presented in the chapter.

Keywords: use cases, PLF, MVP design

16.1 Introduction of IoT and the IOF2020 project

Precision agriculture and precision livestock farming (PLF) are core to satisfying the ever-increasing worldwide demand for food products of good quality, whilst allaying the societal concerns over animal welfare and reducing heavily the load on environmental resources. The principle is that if the needs of animals and crops are satisfied at the highest granularity, the farmers and the supply chain – including consumers – will benefit. Over the recent past, the sector has been subject to an increasing drive towards efficiency and performance enhancement to improve sustainability.

A direct consequence is that the farmers have less time to execute traditional practices and are becoming increasingly reliant on technology. Thus, there is a growing range of opportunities for the delivery of precision farming solutions through the integration of a mix of hardware and software technologies. In turn, the evolution to new business models based on provisioning a range of services

10.3920/978-90-8686-934-3_16, © C. Lokhorst 2022

to the agricultural community becomes possible, fuelling further the ready uptake of technology for the benefit of all operating within the supply chain.

The solutions required to support this evolution harness a number of technologies that follow Internet-of-Things (IoT) principles (Hassan *et al.*, 2015). IoT is a platform that allows a network of devices to communicate, gather data and process information collaboratively in the service of individuals or processes. An IoT system can be characterised by the following typical aspects (inspired by Figure 16.1):

- Sensor(s): a sensor is a device that is able to measure a specific feature of an object or environment. Sensors are responsible for the conversion of the measured phenomena into a quantity, which can be stored in a data acquisition system or in the cloud. The output of a sensor can be e.g. an electric signal (in current, voltage or frequency) which is in the data acquisition system translated in a digital number. In general, the following phenomena can be detected by sensors: biological, chemical, electric, electromagnetic, heat/temperature, magnetic, mechanical motion (displacement, velocity, acceleration, etc.), optical and radioactivity.
- (Home) gateway: this is the system that is responsible for connecting the physical sensors to the Internet. This component is not always needed in IoT developments as sometimes sensors are connected directly to the internet without need for a gateway.
- Cloud/small data management system: to store and handle data and information from the sensor systems and the connection through the (home) gateway to the Internet data storage system(s) has to be arranged and managed. These data storage systems can be either in the cloud or being distributed to diverse locations.
- Data analytics, exception management, rule-based system and alert system: in an IoT system intelligence to transform data into information, knowledge and action should be incorporated. A variety of intelligence solutions are available from data analytics, modelling and artificial intelligence.
- Operator, subscriber, management billing and support system: for an IoT system it should be clear who the operator and the subscribers (or clients) are and how their relation in the form of billing mechanisms and support are organised. This can be seen as the underlying business model for the IoT system that will be based on transactions.
- User interface apps (social media services): the transformed data into alerts or actions need to be communicated to the users. Since the IoT system is also connected to the Internet also a specific designed user interface app or general use of social media and/or platforms will be part of the IoT system.

The EU stimulated IoT research and innovation programs for several sectors. Large scale pilots support the deployment of IoT solutions in Europe through integration of advanced IoT technologies across the value chain, demonstration of multiple IoT applications at scale and in a usage context, and as close as possible to operational conditions. Large scale pilots are targeted, goal driven initiatives that will propose IoT approaches to specific real-life industrial/societal challenges. Pilots are autonomous entities that involve stakeholders from supply side to demand side, and contain all the technological and innovation elements, the tasks related to the use, application and deployment as well as the development, testing and integration activities. For agriculture and food production in Europe the large-scale pilot Internet of Food and Farming (www.IoF2020.eu) was selected and

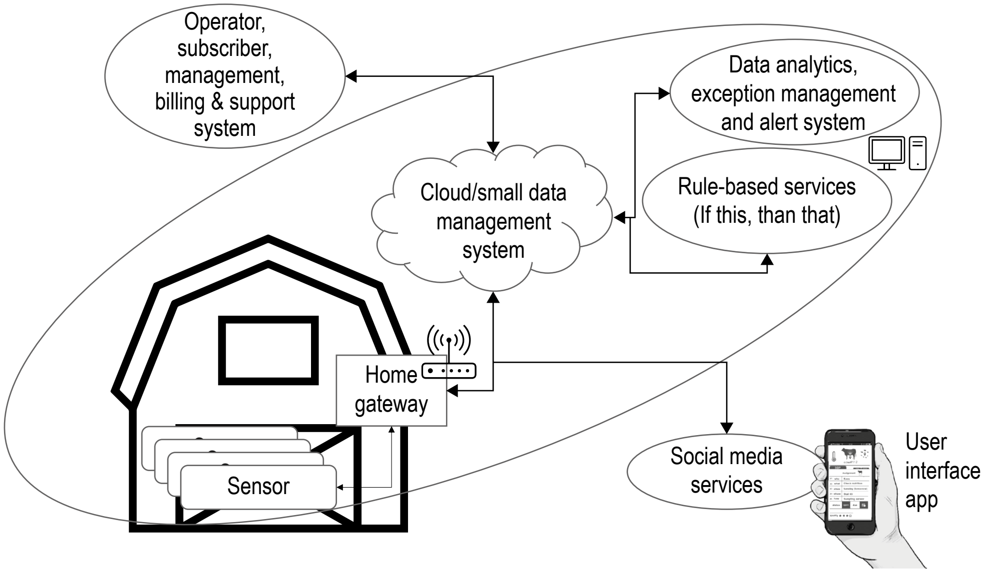

Figure 16.1. Basic aspects that should be part of an IoT system (according to Cees Link from Green Peak).

started in 2017. Agri-food is a very challenging domain for IoT because the 'things' are often living and natural objects, such as plants, animals, m^2 of soil and perishable food products. This means that IoT devices (e.g. microprocessors, sensors, antennas) cannot be easily embedded in the products themselves. And often they have to operate in harsh environments and remote areas (open fields, stables, etc.) so they need to be energy-autonomous and able to deal with internet connectivity problems in rural areas.

The IoF2020 project envisions to accelerate the development towards self-adaptive systems in which smart objects operate, decide and learn autonomously. The heart of the project structure is formed by use cases in diverse subdomains of the agriculture and food sector, including both conventional and organic farming, and an iterative process of working with minimal viable products (MVP). Key stakeholders are users that are convinced of the business benefits and developers that have a clear commercial drive. The activities focus on the optimisation, implementation, and testing of technologies that are near to exploitation. The use cases are grouped in five different trials, one of them being the dairy trial. The objective of this book chapter is to describe the experiences of the use case developers in the dairy trial with regard to the IoT challenges, the practical testing and being part of a large-scale European project.

16.2 Challenge of the use cases in the dairy trial

The challenge of the dairy trial in 2017 was to implement, experience and demonstrate the use of real-time sensor data from 'grass to glass' to create value in the dairy chain for farmers, feed- breed- and food advisors, and veterinarians by applying the FAIR (findable, accessible, interoperable, reliable) principle in using IoT.

World-wide market expectations forecast an important role for dairy chains in Western Europe. The Animal Task Force described the challenges and summarised them under the terminology of 'Big Data: phenotyping and precision livestock farming (PLF)' (ATF, 2016, 2021). To meet policy goals for more efficient use of resources and production of quality foods combined with emphasis on better animal health, welfare and environment, practical options should be sought for combining genetic, genomic, metabolomic and phenotypic information to gain a better understanding of biological processes and to improve (selection) decisions for livestock by exploiting technological gains in these areas. PLF on the one hand, and the genomic revolution ('omics tools and data') on the other hand, are key elements for successful implementation in the breeding sector.

In this Dairy trial we work on the PLF perspective (Lokhorst, 2018). Data, and data management and analysis facilities are necessary tools for handling the huge amount of data relevant to dairy production, and for simplifying the localisation, the extraction and the analyses of relevant information. The development of PLF requires the development of mathematical decision support modelling (e.g. data mining and artificial intelligence), (wireless) sensor technology (including remote sensing and telemetrics) infrastructure (web based, databases), standardisation (e.g. RFID) and user-centric design methods to evaluate the benefits of combining data from different origins (biological, behavioural) and to improve the quality of the diagnosis and support. Data from different systems/sensors needs to be made available for farmers (and in an aggregated form also for other chain partners) and third-party software developers. This will enable development of decision support software for integrated farm management independent of hardware vendors and allow combining data from multiple single signal systems.

The goals are to improve, validate en demonstrate systems for the collection, collation and sharing of relevant data and the creation of protocols for the use of such data in software development for smarter farming systems. Several barriers to sharing of (open) data have to be removed. Farmers are reluctant to give access to their farm management and sensor data, including data on variation within soils, crops and livestock. They want to be in control of who can see and use the big data. Only a few farmers see that this big data can be used as a sign of good agricultural practices and can become a licence to produce.

In the dairy trial re-use of data in the whole chain was an important issue. To support that data could be re-used the idea was that the 365Farmnet platform would be the glue to exchange data of cows. The idea behind this is that cow data can be used for more purposes. On the short term they are needed for early warning for the farmers (see use cases of Happy Cow, Silent Herdsman and Grazing Cow Monitor). But in an aggregated form they are used by breeders (phenotypes), feed advice, veterinarians and food companies for their quality control systems. In chain perspective the use case of 'remote milk quality' will be the experimental setting where quality systems and the product of milk to the consumers will become transparent. Qlip introduces an innovative concept for measuring milk quality with Infrared sensors in different parts of the production chain and this can be used also for remote validation and calibration. They involve the other use cases in the dairy trial and work together with the dairy food companies to explore the potential.

Another challenge in the trial is to integrate location-based information. Location is needed outside and inside the barn. Until now different units for location are used inside and outside. For the outside location we will build on the Belgian Grazing Cow Monitor use case where the challenge is to use global positioning system (GPS) technologies and network technology. For inside location determination that use case will make use of ultra-wide band technologies. To demonstrate and experience interoperability we will build on two use cases with different cloud-based services and technology (SilentHerdsman+ and HappyCow). Both are based on neck collars and information supports farmers on feed efficiency and early warning for health and welfare. User-centric and iterative improvements are needed to demonstrate it and focus is also on the data analytics to make sense of sensor data in a diverse environment.

The dairy trial started with the four mentioned use cases. The idea was that the selected use cases were driven by an industrial partner and that small use case consortia were formed that should align their activities. In the IoF2020 project there was budget allocated to bring in through an open call additional use cases in the 3rd year of the project. The open call was calling for use cases realising IoT based solutions in the agri-food domain, addressing new regions and/or post-farm or other sectors in the agri-food domain. This open call process resulted in 3 additional use cases that were added to the dairy trial. The three use cases were UC2.5 MELD with the challenges to integrate existing lameness detection as a service into the IoF2020 architecture and validate machine learning as a tool for early lameness detection. UC2.6 Pitstop+ has the challenges to integrate precision mineral supplementation of dairy cows and to have the system working in a challenging dairy environment with high variations in temperature in a dusty and humid atmosphere with high concentrations of ammonia and other aggressive gasses. In use case 2.7 Smart Precision the challenge is to realise a measuring device that operates *in vivo* and capable of assessing a set of parameters that can be communicated to an external infrastructure where decentralised data provide the input for datamining and machine learning based forecast, alert and predictions.

Based on experiences in the first two years of the dairy trial and the addition of the three new use cases we had to leave the idea that we could test interoperability and the connection to the platform 365Farmnet. All use cases operate independently and take their own responsibility for MVP development. The project environment stimulated learning from each other, drives the use cases in their development and testing to show practical results and offers the ability to be in contact with experts on technological, business and ecosystem issues. This reality is shown in Figure 16.2.

16.3 Description, development, innovativeness, testing and showcasing of the use cases

In this paragraph all the 7 use cases of the dairy trial will be introduced and experiences in development, testing and showcasing will be described. After all use cases are described independently, the common experience will be discussed. Information is extracted from the IoF2020 website, the IoF2020 catalogue and the periodic reports from the use cases (NN, 2021)

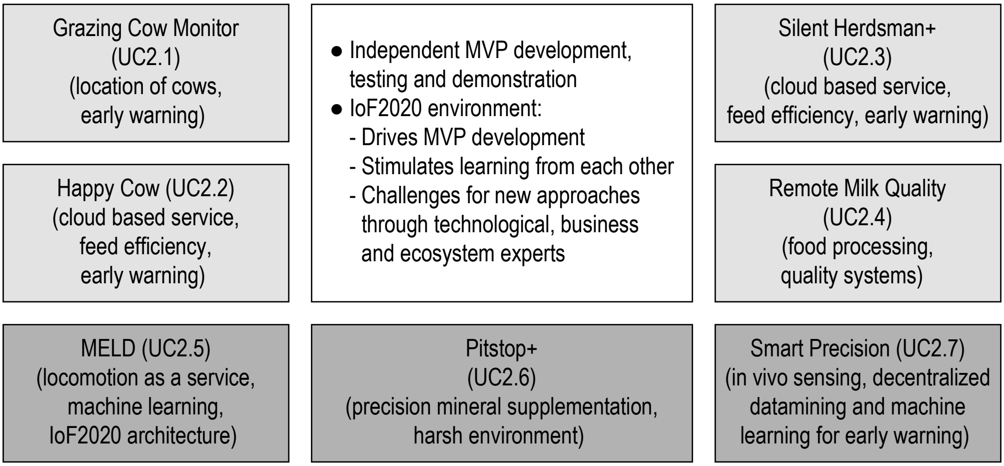

Figure 16.2. Schematic view of 7 use cases in the dairy trial (light grey = initial selected, dark grey = added through open call).

16.3.1 Grazing Cow Monitor (UC2.1)

Sensolus, Inagro and ILVO worked together in the use case 'Grazing Cow monitoring'. Sensolus is an SME with its roots in IoT solutions outside agriculture. Inagro is an advisory organisation in Flanders and ILVO is the Flanders research institute for agriculture, fisheries and food. The original challenge was to build a system that is able to track the positions of individual cows and to determine whether a cow is indoors or on pasture. Data on the time and location of cows enables farmers to significantly decrease the time looking for cattle, to control ammonia emissions, to automate proof of pasture time, to proof emptiness of barns and to label milk as coming from cows that are grazing in pastures. Key element in the solution is the use of trackers that are mounted on a neck collar, can work with a GPS and Bluetooth low energy (BLE) signal to determine its position indoor and outdoor, communicate this to the cloud by using a Sigfox network and present the data to the user on different platforms. So, almost all characteristics of an IoT system are present in this use case.

MVP1 development started in 2017, trackers were attached to cows using neck collars, specific algorithms were designed to monitor in/outdoor position, geo-zones and alerts were incorporated and the MVP was tested and validated under coordination by ILVO. During MVP development and working on the business case it appeared that the costs-benefits for the dairy farmers were not strong enough at this moment for digital recording of milk from pasture with such a system. It would be better to focus on beef cows rather than on dairy cows. In several interactive sessions the business case was discussed. But as this is not the core business of Sensolus, domain knowledge is needed for these extra developments. Sensolus preferred to stop the development at the reached MVP and looked for an agriculture/dairy partner for further feature development. Sometimes they had the feeling that the ambitions were too high having to think of all kinds of additional functionalities. Currently farmers proof that they provide milk from cows grazing in the pasture is not very strict. So manually recordings are still the cheapest way. Another, more viable business case was found and that is the tracking of beef cows or other livestock in nature grazing areas. Therefore, the MVP1 development of the grazing cow monitor was finalised for dairy cows and a second product line (MVP2) was developed for beef cows in nature grazing areas with their specific requirements. The MVP2 tests and interaction was done on a farm with 83 beef cows that were living in the Drowned Land of Saeftinghe (3,000 ha of which 230 ha available to the cows). This is an area were salt and brackish water floods the land. This salty environment gives a special taste to the meat of the beef cows that are used for grazing the area, but also forms a challenge for the cows to survive. Getting trapped in ditches can be a severe risk of losing cows in the floods. This in turn causes stress and worries for the farmer, and when a cow gets missing an extensive search has to be done in order to hopefully find and rescue the cow in time.

Technical challenges had to be solved on the attachment of the sensor, the casing of the sensor, the algorithm definition to be able to detect 'being trapped in the ditch of a cow' and the real-time dashboard features for the farmer. Key element in the solution is the use of trackers that are mounted on a neck collar, can work with a GPS signal to determine its position, communicate this to the cloud by using a Sigfox network and having a user interface so that he can see where the cows are, how many cows are still active and even when a cow is in danger.

During the development and the in testing MVP the attachment and casing of the sensor has been proven suboptimal leading to a high number of trackers that went offline in MVP (due to the fact that the tracker fell from the top of the cow to hanging under her neck where no GPS connection can be made and no location information can be sent to the platform) and although the tracker is water and dust proof (IP69) it was not robust enough for the environment it was used in, and even a number of animals losing the trackers in the field. These items were addressed by rethinking the attachment and extending and testing the water increase of the sensors Therefore other neck collars and a new way of attaching the trackers was tested. Trackers were checked in the laboratory and an in-depth analysis was done on the following topics:

- Cloud inspection: looking into the diagnostics metrics provided by the Sensolus cloud platform (number of GPS fixes, Sigfox quality, last send messages, etc.).
- Visual inspection: we inspected the (1) attachment of the tracker to the neck collar; and (2) when cautiously opening the tracker a visual inspection was executed on water insert, corrosion and visual abnormalities.
- Battery inspection: the batteries were taken out and a battery measurement was done to see if the problem was related to a battery drain. Battery drain is often a consequence of another problem.
- New batteries: new batteries were put in the tracker to see if the tracker restarted by putting new batteries.
- PCB inspection: on very detailed level we looked at the PCB to detect if there were any problems.
- Current measurement: after new batteries were placed the battery drain was monitored.
- Debug firmware: the tracker was re-flashed with an analysis firmware version to get access to firmware information that only can get accessed with the analysis firmware version.

Water intrusion was clearly an important reason for the fall-out of the trackers in addition to some bug issues related to the tracker firmware. After analysis the assumption was that the origin of the water intrusion was the venting membrane. The membrane is important to get humidity out of the tracker when the tracker is used in locations with different temperatures. A 100% humidity free tracker doesn't exist for objects that reside in locations with different temperatures. The only way to be sure water is vented out is to use a venting membrane. The problem with the usage of the tracker for cow tracking is that cows are sometimes residing in really wet environments (especially when they got stuck in the ditches). Sensolus decided to seal up the membrane for usage of the trackers in the agriculture sector. Therefore, an epoxy glue was used to seal up the membrane on a set of trackers that where then used to test the waterproofness of the tracker after membrane closure. The results were good and we decided to seal up all cow trackers.

Given positive test results, the improved attachment sensor and attachment was implemented for all animals (83) at the test site. In addition, a user guide was developed in order to allow the farmer to ensure optimal attachment of neck collars and trackers. The results can be considered as extremely positive as the total loss of trackers during the test season has been reduced to zero. In addition, the number of trackers that went offline due to friction and movement of trackers at the collar has also dropped to not been notified.

Algorithm and software development was also influenced by the new validation roads and end-users in nature grazing beef cattle. Case specific requirements were fine-tuned such as to enable a find you cow navigation tool, geo-zone set-up and tracking in/out geo-zone on individual cow basis and additional algorithms were developed in order to generate more appropriate alerts (e.g. snapshot of location update of all cows on a certain moment; if a cow is out or in a 'Geo-Zone'; if a cow is not moving for a predefined time; if a cow is too long out of a 'Geo-Zone' (e.g. drinking zone).

It was key to continuously incorporate feedback of the farmers using the Sensolus system. This follow-up was demanding almost daily calls with the farmers, mostly done by the project coordinator at ILVO. This considerable time investment would decline if the automated decision and alert system was optimised. This was also the goal of this trial, a further automatization of the alert detection. Farmers were asking for a direct communication with the developer at Sensolus. This was not very helpful because no helpdesk information was available on the Sensolus helpdesk platform on the cow tracking use case and the direct contact with ILVO was well adopted to the use case.

Different demonstrations were organised to show and discuss potential of the solution. In general the use of the Sensolus solution for nature grazing was very positive: (1) the use of the solution enabled to optimise time management: 'My physical time spent on the field looking for cows on a daily basis significantly decreased.'; (2) the solution resulted in a stress reduction 'The ability to track and know the position of each animal at any given time significantly decreased my stress'; (3) the Sensolus solution has economic value through proven return on investment (ROI): 'Within the test period, 2 cows that were trapped, have been saved from death by drowning. This means a recovered potential revenue loss of ±5,000 Euro for me compared to a small investment for the solution'. In addition, the farmers of the test farm indicated that the Sensolus sensor was also helpful in identifying lame animals due to the distance covered in a predefined period might be less than other animals.

Given the positive results at the test farm and the multiple communication though different media channels, other farmers were asking if it was possible to implement the solution at their site. In the meantime, also tests with sheep have occurred. Sensolus should develop a sales and marketing strategy or find a distribution partner for agriculture to address these questions, this is on-going at the moment.

16.3.2 Happy Cow (UC2.2)

Connecterra from the Netherlands builds IoT based solutions that combine big data analysis with machine learning technologies. They support dairy farmers by giving them insights to understand their cows better, detect issues at an early stage and gives suggestions on potential solutions to increase farmers productivity. The core of the intelligent dairy assistant (IDA) system is the Artificial Intelligence part that is based on machine learning and that aligns with decisions or instances that farmers normally are confronted with. IDA gives insights to the farmer, which means that it tells what is going on and what the farmer needs to do to resolve it. This means when a cow is in oestrus, IDA gives advice on insemination. Or when the behaviour of the cow signals a health problem, then IDA offers the farmer a list of health issues that might be related to perceived behavioural pattern. The farmers give feedback to the system on whether they agree with the IDA insights, including information that explains the behaviour of the cow (e.g. a particular disease). This allows Connecterra to train their system, become smarter over time and improve/measure KPIs dynamically. During development the underlying AI models were improved and adapted when necessary.

Data input originates from different sources. The basic source is a neck collar with an accelerometer that is sensitive enough to measure a variety of movement patterns. During development the accelerometer data are trained by specific observations. To be competitive in the market initially it is trained on oestrus detection, mastitis detection and feeding abnormalities. Later on, they started to work on lameness detection and environmental abnormalities. This work was supported by researchers and students from Van Hall Larenstein University of Applied Science and Wageningen Livestock Research. Like in all collar-based systems, battery life time improvement is a key challenge. Connecterra has worked on improving energy consumption, firmware and battery optimisation. A major improvement was that it became possible to run an AI client on the tracker to translate sensor readings into behaviours. This reduced the data load that needs to be transmitted to the base station and hence saves battery life. Adjustments were also needed to the casing of the sensor. It now consists of a 2-component system that clicks together and is more robust.

The second source of data are coming from farm management information systems (FMIS). Basic cow data on insemination dates, pregnancy check results, milk yields and treatments with antibiotics production, lactation and others are also used in the IDA system. The main reason is that it is commonly known that detection of abnormalities should be based on multiple data and advice also depends a lot on the context of the data. An advice for a cow in her 8^{th} parity at the end of lactation differs quite a lot from a first parity cow in the begin of her lactation. FMIS all use their own database architecture. Therefore, there is no standardised way to access farm data and no uniform data format. Connecterra has gained experience in connecting to various FMIS. The problem is complex because every supplier uses its own formatting standards and different software architectures. Connecterra developed an automated system that can connect to a range of farm management systems, process the data and store it into their own database which we connect to our IoT platform. In the meantime, Connecterra connected their IDA system to more than 14 different FMIS.

The third data source are the farmers, being the users of the IDA system. They have the ability to provide direct feedback on the suggestions IDA gives. During the IoF2020 testing also monthly sessions between farmers, Connecterra and specialised advisors from ZLTO and VetEffect were organised to discuss the observed trends in the data and the IDA generated advises. Based on this user interaction Connecterra decided that the original restyling plans for the app would not result in an app that is more suitable for farm management. The original redesign would have essentially replicated the already existing functionality in a more attractive appearance. Using the available software technology to build an app that really helps farmers, required a more thorough process. Also based on farmers needs a herd ranking feature based on individual feed efficiency has been developed and deployed amongst their farmers. The ranking is intended to support breeding and culling decisions. This tactical management on dairy farms is complex, because many tangible and intangible criteria influence such decisions. Therefore, farmers indicate that they would like to see more criteria included in the ranking. Based on this feedback Connecterra is exploring the possibilities to quantify and add additional ranking criteria such as reproductive efficiency.

Furthermore, Connecterra learned that variation in management of dairy farms across the globe will give different demands for their platform. For instance, in New Zealand dairy farming is strictly pasture based. This means that cows come to the milking parlour twice or three times a day and otherwise the cows are out on pasture where they remain out of reach for the base station and out of sight for the farmer the rest of the day. This means that IDA has a short time window to off load and process data and notify the farmer. The farmer can only intervene when the cows are at the milking site. We learned that for each new country and farming system we need to carefully consider the local conditions and management practices and figure out how these impact IDA's performance.

Since Connecterra works globally a challenge is on the data infrastructure and data communication. In rural areas internet connections are often limited in capacity and stability. This negatively impacted the response time and caused congestion on the IoT platform of Connecterra. Furthermore, the number of clients grew and their farm size increased. Increasing the processing capacity of the cloud in itself was insufficient to solve these issues. Therefore, a redesign of the IoT platform and data pipeline was necessary. The data pipeline redesign was critical for the stability and performance of the IoT solution. The basis is IoT Edge computing in which important functionalities are processed in a decentralised manner. Independent of the central processes on the servers of Connecterra. This new setup also means rethinking all dataflows and model implementations. Therefore, this consumed a lot of time from the engineering, hardware and data science teams, as the whole process from sensor to app needed to be rethought, redesigned and tested. Based on an iterative approach, which includes the IDA feature set, the IDA platform has grown, changed over time and became more stable and reliable.

In the IoF2020 project IDA was tested at several farms. Tests at a Belgian and a Dutch farm, both with 100 milking cows, were quite successful. The test lasted more than 2 years. The test was designed such that half of the population of cows were managed by using IDA as advisor and half of population were managed without using the IDA advice. The idea is that this approach comes near the ideal situation of having the test before and after installation and with an without the system to test. Following these two groups on two farms resulted in good data on KPI's to follow. However, testing the IDA system in a German and an Irish farm caused problems. In Germany the size of the farm caused some problems in terms of coverage and data transmission. Furthermore, setting up a reliable internet connection was a challenging effort. For the farmer it was also very difficult to split his herd in two groups. After solving these issues testing started with an alternative approach. The test at the Irish farm was stopped because the collaboration was difficult and promised data could not be delivered. Data collection, internet connection and access to farm management data turned out too tough to solve in the Irish farm. Especially the farm management system, which turned out to be an outdated stand-alone solution.

16.3.3 Herdsman+ (UC2.3)

Herdsman+ harnesses the experiences and know-how acquired by an engineering team from the University of Strathclyde in Glasgow, Scotland during the development and commercialisation of the Silent Herdsman neck-mounted collar platform. The accelerometer-based collar was designed initially to identify the onset of oestrus in order to optimise pregnancy rates but was extended to provide the time spent eating and ruminating at an individual animal level, proxy measurements that indicate the onset of an illness condition. The start-up was acquired by Afimilk and the Silent Herdsman system – renamed AfiCollar – is currently offered as one of a suite of products.

The group at University of Strathclyde has continued the development of a new range of IoT-enabled data-driven solutions within an academic environment with UC2.3 focusing on the definition and prototyping of cloud-based services that promote the implementation of precision dairy management. The solutions are predicated on the integration of data from a number of on-farm systems facilitating the creation of an enhanced operational decision support platform, in turn yielding greater benefit than that derived from individual systems. Each additional data stream will enhance the understanding of the practices across the farming environment and render any decision support application more robust in its diagnostic capacity. Integrated data can be mined for variances (both individual and combined) that enrich the understanding of animal behaviour and on-farm processes. A mix of alerts generated with real-time data, e.g. health act as pro-active guidance on any emerging issue that requires an intervention. Furthermore, data capture can be envisioned across the production chain and the resultant information shared with a range of stakeholders to streamline the supply chain and increase the provenance and safety of dairy produce.

UC2.3 has interrogated data from Silent Herdsman neck-mounted collars, Fullwood milking robots, feed data from Keenan mixing wagons and location from the SmartBow system. The biggest challenge in integration was the reticence of suppliers to grant access to their data. The sharing of data at the commercial level is relatively immature as the concomitant value proposition remains to be proven. Although the benefits to the farmer are clear as a unified data pool facilitates the mining of more accurate information and input data need only be entered ONCE – currently the user must input the same data to each on-farm system. The technical challenges, although non-trivial, are surmountable if the suppliers are willing to engage and provide information on their existing data format and database schema. Issues with the time synchronisation of different data flows have to be managed. As UC2.3 is being driven by an academic team, access to data is less commercially sensitive and several streams of data have been integrated on servers at the University of Strathclyde. The initial exemplar of the benefits of data integration centred on analysing data from collars and milking robots with focus on mastitis detection, a key illness condition that compromises milk yield. Results show that a drop in the time spent eating/rumination as provided by the collar system was evident in advance of the rise in the conductivity of the milk, a measure used within the milking robot system as an indicator of the onset of mastitis.

However, the development of a scalable web-based platform is a far greater commercial challenge than that can be delivered through an academic-led use case. The challenges identified and lessons learned from *Herdsman+* guided the selection of a suitable commercial agri-themed web platform, stimulating the engagement with GlasData. The coherent integrated database is the foundation for the UC2.3 team to focus on data analysis and algorithm development using the aggregated data to enhance models that identify closely correlated features related to animal health.

The integrated data has allowed the development of a range of additional models. The analysis of each data stream is governed by the type of data. The majority of data are time series and are analysed initially using statistical methods to identify useful trends that can be verified through additional data sources (visual observation). Significant data cleansing is required at the outset to ensure that the analysis does not consider 'outlier' samples. For example, collar data is analysed using clustering methods to derive different animal behavioural states. The classified data is then used with decision tree algorithms to make predictions on future animal health. Regression methods are used to monitor milking robot data such as fat to protein ratio over time which, when combined with collar data and milk yield, per-quarter yield, conductivity is utilised to predict the onset of clinical conditions such as mastitis. Currently feeding and rumination are providing the most reliable early indicator of welfare issues but additional information, e.g. milk conductivity enables a higher degree of specificity of illness. Another model approach focuses on detection of standing and lying based on the activity collar outputs using training data from leg mounted pedometers, allowing cross-validation of animal states. The approach is driven through the development of convolutional neural networks and machine learning that allows very large cattle datasets to be processed quickly. Collaboration with other UCs within the dairy trial with a view to correlating data derived from UC2.3 with use case MELD's lameness detection algorithms and with Pitstop+ mineral supplement was carried out.

The identification of an appropriate data integration/visualisation platform (GlasData) aided the development of *Herdsman+* significantly, enhancing data analysis and algorithm development. An internal visualisation application was created to display the raw data, daily summaries and the outputs of the algorithms but proved challenging due to the complexity of the web API development. Consequently, the UC2.3 conducted a review of appropriate technologies and identified a platform which is both scalable and can enable the easy integration of data from existing on-farm systems.

The GlasData platform (https://glas-data.co.uk/) is currently used by a large network of farmers for visualising existing single source data streams. The approach to visualising data utilises a unified timestamp, the activity collars being the reference with other systems set to the same sampling frequency of 10Hz. The platform has allowed a baseline to be established on key parameters such as the time spent ruminating and eating with the database hosted at the University of Strathclyde and the visualisation executed by GlasData features.

Practical deployment and showcasing of the outputs of UC2.3 was executed on a dairy farm in the UK. Parkend (PARK), located near Cowdenbeath in Scotland, is one of the main satellite farms established and supported by the Agricultural Engineering Precision Innovation Centre (Agri-EPI), one of four UK Government Centres of Agricultural Excellence facilitating access to data. Data gathering at PARK concentrated on streams from the milking robot providing alerts and continuous data parameters – milk yield, time between milking, milk fat, milk protein, electrical conductivity and milk lactose content – integrated with data from the Silent Herdsman system. Currently, the end user needs to input key information on each animal on four different databases. The integration approach uses a locally housed database with all data collated into a single off-site database access available for analysis and dissemination between partners. The gathering of data is continually reviewed to ensure that operational issues are identified quickly and rectified. For presentation to the farmer, daily summaries are preferred as the level of detail normally requires for algorithm development is far too granular.

The *Herdsman+* database has been designed to allow drill-down of daily summaries, enabling the user to interrogate more granular data if desired. The design and deployment of a more functional platform for integrating all of the on-farm data is ongoing. Relevant data sources are acquired daily or hourly through a batch process with the outputs reflected back to the farmers through a Graphical User Interface (GUI). In the absence of commercial data sharing agreements, vendors are more amenable to providing a data dump rather than enable an automated exchange of data between systems. The target GUI, the development of which is challenging and requires continual input from end users, must provide a dashboard that farmers can interpret easily and guide the most effective action.

16.3.4 Remote milk quality (UC2.4)

Qlip is a specialised central milk and dairy testing laboratory in the Netherlands. They use InfraRed (IR) instruments to analyse milk composition and quality from all the dairy farmers in the Netherlands and they are in direct contact with all the milk processing plants. However, it is a challenge to keep analysis instruments well calibrated, controlled and monitored throughout the dairy chain. Therefore, this use case envisions a quality assurance service of locally obtained milk and remote dairy composition analyses through the use of sensor based IoT applications. Analytical instruments will be monitored remotely and validated by use of reference samples, calibration sets and software applications. If necessary, adjustments can be carried out remotely.

At the start of the IoF2020 project Qlip did not had any experience with IoT based applications. Although they have a highly digitised process with a lot of procedures and data exchange they were quite new in IoT. For that reason they needed some interaction with experts to be able to define their first MVP. It should be focused on the calibration process of instruments used in dairy processing plants. The remote dairy quality (RDQ) app will be used by the process operator. The application monitors if the calibration plan is executed properly. If not, an alert will be generated and send to the responsible manager. The following functionalities are available in the RDQ app: (a) scanning of reference sample (QR-code or barcode), (b) standard operating procedure for adequate sample handling and (c) input of test result (manual). The RDQ app issues the following alerts: when execution is not compliant with the plan and when the test result is out of specs/limits based on control charts. All alerts are also available in the customers portal and Qlip will also monitor alerts and will take action when needed. A functional design of a first version of a RDQ service tool was finalised and a prototype was tested. The RDQ-tool is introduced to customers by 1-1 visits and workshops. Delivered within a total package of calibration products & services (on-site calibration support, control and calibration samples, training and RDQ-tool for calibration management). Already in this development phase 2 customers have invested in the RDQ-tool, and it is used daily and used at multiple production locations. Discussion started with laboratory equipment vendor capitalists to bring the product to the market. However, these discussions were not successful. Main reasons are (1) one vendor is developing and promoting their own calibration approach of their instruments. This approach differs from Qlip's approach and is not easy to align with the RDQ-tool, (2) another vendor is acquired by another company and are internally focused on a new organisational structure and have no time available for this project.

Qlip organised an open challenge where other organisations could come up with IoT based suggestions and solutions that might fit the organisation. This was a very creative process and quite some suggestions were made. This led to the design of the second product. A design for a 2-minute Sample Pre-Treatment device was made which could be seen as an addition to the RDQ-tool. This saves the process operator time that he currently has to wait for the sample to heat up in a water bath. Furthermore, the unit stirs the sample to a homogenous sample ready for testing. At the best, this is going to save our clients time (and costs). The chosen design is presented to the Qlip management and a proposal by an external partner was made for the development phase. Based on a market research Qlip had meetings with a number of potential partners with IoT experience. Eventually they decided to team up with the Dutch based firm Axians Performance Solutions. Initially the sample pre-treatment device is received positive by the management team. However, to take a good decision there was a need for more information on the business case. They developed a business case for the sample pre-treatment device. To validate the business case, they interviewed customers. The outcome of this validation was not positive. The costs were perceived too high against the benefits of better and reliable measurements on dairy processing level. The Qlip management team then decided to put this product development on hold as (1) the business case wasn't valid, (2) lack of resources, and (3) activities of 3rd party (Axians) could not be part of the IoF2020 project.

The third product Qlip is working on is the development of an IoT Communication platform to support and exchange data with remote milk testing devices on milk transport truck level. Normally the milk transporter takes a sample of the tank milk every time he collects the milk. These samples are sent to the central lab and are analysed there. The new product should be able to reduce the workload of the transporter and a very futuristic version is that analysis can already be done trustworthy at the farm/truck. Qlip drafted, together with an expert from the IoF2020 project an architecture framework. Together with another expert and support of ZLTO a preliminary business plan has been made. Also, a dashboard has been designed for technology partners to get an overview of their managed farms including KPIs on how the farm specific models are performing. An interface for the truck driver and an interface for the operator for calibration and performance management has been designed. Based on these preparations development of a prototype started in 2020.

16.3.5 MELD: early lameness detection through machine learning (UC2.5)

The Waterford Institute of Technology (WIT) from Ireland applies machine learning to identify lameness in cattle in an early stage to increase animal welfare and lower treatment costs. They work together with ENGS Dairy and Herdsy who provide commercial sensors that are based on accelerometer technology and with University of Strathclyde in data analysis and model development. The initial algorithms were developed using the pedometer technology from ENGS, whereas the new vendor Herdsy utilises a collar-based system for herd tracking. Lameness is a considerable problem in the dairy industry. It causes pain and discomfort for the cow, while lowering fertility and milk yield. Since current solutions come with high-initial costs and complex equipment, this use case wants to benefit from an IoT based solution. The MELD system utilises leg mounted sensors measuring step count, lying time and swaps per hour, in combination with machine learning algorithms to identify lame cattle at an early stage. These data are analysed in the cloud and anomalies are sent to farmers' mobile device to treat affected animals immediately and avoid further effects. As opposed to a general approach, this use case customises the data models to dynamically adjust as weather and farm conditions change. By detecting early lameness before it can be visually captured, treatment costs are decreased while animal welfare is improved.

The first technical challenge is to integrate an existing 'Lame Detection as a Service' (LDaaS) into the IoF2020 Architecture. WIT worked already with an existing testbed and trial infrastructure, and they wanted to integrate it in the IoF2020 reference architecture through the interoperability points made available to other third party services running the IoF2020 reference architecture. For this a reorganisation of the technical deployment was undertaken which involved scaling the original technology to operate with multiple vendors across multiple farms. Also, the entire deployment was migrated from an IBM cloud infrastructure to an in-house open stack cloud infrastructure. This includes the development of automation scripts to scale for multiple vendors each deploying on multiple farms, which was a considerable undertaking job. The integration with the IoF2020 reference architecture needed remodelling of the data outputs from the platform into NGIS v2 compliant data models and exposed through an NGIS compliant API via the Orion Context Broker. Development of a mobile app for farmers to manage the lameness detection lifecycle was done. It is now available on iOS and Android and includes secure authentication and feedback mechanism to aid model re-training. Each of the trial sites has a set of machine learning models specific to that farm. A mobile app is used by the farmer to manage the lameness detection lifecycle and this includes the ability for the farmer to give feedback on the detection alerts which provides re-training data for the farm specific models. The machine learning models use data collected every 6 minutes and the early lameness detection algorithm uses aggregated daily data on steps per day, minutes lying per day and number of changes from lying to standing per day. All data that flows into the algorithm of the service produce additional knowledge. So, this includes in a first level only basic hardware related data like values from sensors and farm machines. In a second level this includes inputs from other services like a full weather map or a feed composition plan for example. Basic non-interpreted data on the 1st level and 2nd level is actually knowledge data in a form aggregated from third party services.

The initial trial was deployed on a dairy farm in Waterford Ireland. This farm was no longer in a position to continue the trial over the test period. WIT set about to recruit a new farm and quickly identified Ballyhussa Farm in Co. Waterford as an ideal candidate. This farm has a similar herd size and a similar environment but uses a DeLaval robotic milking system which provides a different scenario in that there are no longer daily observations of all cattle. The equipment was re-deployed and while this took some time to redeploy, there was no significant impact on the use case. The trial deployments are in place and data are being collected. In total there are initially 845 cows being monitored for lameness in Ireland, Israel and Portugal. In the South Africa case, where the Herdsy equipment has been deployed, a Sigfox signal issue has delayed the data collection until a Sigfox micro-base station was deployed on the farm. The South African national Sigfox operator had initially indicated that the signal was available on the selected farm through their coverage map. In reality, the signal was very low and the gaps in the data were too large for meaningful analysis. Another lesson learned was that based on a misunderstanding on behalf of WIT meant that the use case pre-financing was inadequate for the purchase of hardware required for the trial deployment. As a large proportion of the funds for both ENGS and Herdsy were related to hardware purchasing, the initial financial distribution was not adequate. Therefore, it was necessary to find and implement a contingency plan. This was achieved through the development of a risk plan within WIT in order that the required funds could be distributed. This took 3 months to finalise to the satisfaction of WIT finance department and caused a delay in the deployment of the trial sites. This delay had a knock-on effect in the case of Herdsy who missed a manufacturing window and delivery of their hardware was further delayed.

To develop suitable business models for the MELD application and deliver a comprehensive business development plan incorporating market analysis, marketing and sales strategy, resource planning and financial projections the WIT team undertook a pre-commercialisation course organised by the NDRC in Ireland. This course comprised a set of modules. Modules included problem definition, customer discovery and validation, value proposition, market opportunity and pitch preparation. The outputs provided an initial identification of the market potentials and an early outline business development plan exploring potential exploitation avenues. Initial discussion with the technology partners of UC2.5 indicated that the commercially sensitive data from the provider could not be shared with other partners outside the use case. As part of the technical trial feedback on the commercial viability of the result will be sought from both of the vendors. Further IoT vendors will be sought through the commercialisation activities and consulted with to validate the commercial viability of the product.

16.3.6 Precision mineral supplementation (UC2.6)

The Organe Institute from Denmark is very active in bringing the concept of precision mineral feeding of dairy cows to the market, since it can reduce resources and benefit animal welfare and the environment. 80-90% of economic losses due to health-related issues in dairy cows appear in the critical transition period from 2-3 weeks before and until about 3 months after calving. Correct and adequate mineral supplementation in that period is of fundamental importance for challenging this development caused by the expanding use of total mixed rations (TMR) or other standardised feeding and management systems and would improve productivity. This use case involves precision supplementation of dairy cows and applies the IoT concept, using an advanced mineral feeder, cloud-based services and data integration combined with the identification of cows via electronic ear tags, thereby allowing tailored and individual extra mineral supplementation on cow level. Minerals and vitamins are important for cows' immune status, and feed additives can furthermore have wide impacts on environment and climate. The data gathered is displayed in a web application to provide easy access to monitor the feeding habits of individual cows, which may be an early indicator for health problems. As a result, this use case's dairy management tool significantly contributes to animal welfare and the resource efficiency of farms. The Organe Institute works in this use case together with the Futterkamp (LKSH), Lithuanian University of Health Science, Union 'Farmers Parliament' (ZSA) and the University of Strathclyde in the scientific aspects of the application and the user interaction with farmers to explain and stimulate a re-thinking of mineral supplementation. In the development and testing, beside 6 farms, also a number of subcontractors are involved. These are part of the ecosystem of the Organe Institute. This fits to the objective of raising awareness about precision mineral supplementation and its foreseen impacts on dairy farm economy, animal welfare, increase the knowledge to IoF2020 and EU support and mobilising of the use case and its partner organisations. Awareness was created at three stakeholder demo meeting events with in total 80 participants, representing a variety of different stakeholder groups.

The Pitstop+ system consists of a few modules. The Pitstop+ feeder identifies, based on ISO standardised electronic ear tag, if the cow is allowed to receive mineral supplementation, and in that case the status for consuming the allocated amounts. This is based on settings of the Pitstop+ Manager that is used in different languages. Pitstop+ Manager is a progressive web application (PWA) and as such it functions on all platforms like a web application, and as well as native apps for Android and iOS. Due to this setup the end users will use their existing devices, such as mobile phones. Cow visits to the feeders are monitored and can be shown to the farmer by using Pitstop+ Manager. To support users a set of guidelines for installation of the feeders and guidelines for installation and use of the Pitstop+ system has been made. The hosts of the Pitstop+ systems were trained in advance.

On the technology side some issues occurred. The situations at the different markets were very useful to get an insight into, for instance if dairy cows are tagged in the left or the right ear, and how the herds are managed. Unexpected interference of signals from GEA CowScout transponders at one of the testbeds in Latvia caused a change of the testbed, as a technical solution could not be quickly developed, also due to the constraints the COVID-19 situation caused. As alternative an additional testbed in Denmark was included. During the testbed activities, almost all hardware components of the feeders were replaced with better ones. Encountered technical issues included cabling, connectors, power supplies and shielding of the electronic components, which in the first MVP quality was not of sufficient quality. Flowability of the mineral feed supplements delivered to the German testbeds was not always good. It turned out that not all of the testbeds used electronic ear tags on beforehand. The decision by most testbed herds were that they would start using electronic ear tagging of their entire cattle stock on a permanent basis. The implementation for tagging followed a different pattern in the different farms, but they clearly all started to give the test cows an electronic ear tag and to tag as well, the new-born calves. Organe Institute was extremely satisfied with the decision of these four testbeds and sees this as a sign that they trust and believe that electronic ear tagging of cattle will be needed in the future for more and more dairy farm management purposes. For instance, one German testbed took the decision so that they also could use an automated calf drinking system on basis of identifying the calves with electronic ear tags at a cost of €2,50 extra per calf, rather than using transponders for the calves for at least 10 times higher price, and the complexity of parring unofficial transponder numbers with ISO standardised official animal ID's.

Preliminary results of the effects of precision mineral supplementation in farms in Germany, Latvia, Lithuania and Denmark with a total of about 2,700 dairy cows are uncertain and tentative but shows convincing results. From two testbeds, where the trials were running most smoothly, the preliminary test results suggested a net value of precision mineral supplementation in the range of €60-100 per cow per year. In addition, the testbeds will have an opportunity to unlock the full potential of precision mineral supplementation after the testbed activities with division of cows in test and control groups are completed, and implement savings on mineral feeds by reducing the amount and quality of mineral feed supplements given via the TMR ration to mid- and late lactation cows. These savings are typically in the level of €10-35 per cow per year, dependent on the use of feed additives in the TMR minerals. The expectation was 3-4% impact on productivity and 10% less disease treatments. The productivity impact expectation was mainly based on trials with RONOZYME® RumiStar™, an amylase feed additive, but from the practical testbed activities, we could not reproduce the scientific results. On the other hand, preliminary analyses suggest additional effects on milk quality and cows' fertility. Mineral supplements are produced by different companies and they have exotic names like 'Pitstop+ ProMais StartLact', 'Milkinal® 8339 Pitstop+' and 'Metabolic Booster'. Practical implementation of the Pitstop+ was influenced by farming factors such as combination with pasturing and the way cows were grouped. From start of the 12 months testing period, every second cow was in order of expected calving date assigned to the group with access to extra mineral supplementation (test cows) or to the group that did not get access to extra mineral supplements (control cows). In general, test cows received extra mineral supplements from three weeks before the expected calving date and until 98 days after calving. Futterkamp developed a special disease treatment registration form to be used by the testbeds in case they did not have other ways of disease treatment registration system. Herd registrations were collected on a monthly basis from testbeds.

Organe Institute was for the testing using a manual, quarterly procedure of registration of expected calving's, and this is working smoothly. However, they also established on a permanent basis electronic data transfer according to a specific protocol with the Danish cattle register held by SEGES, ensure the information about the cows always is updated and precise. Such protocols for reuse of already registered cattle data does unfortunately not exist in the other involved counties, Latvia, Germany and Lithuania. It is very important for the accuracy of the Pitstop+ system operations that cows expected calving date is replaced with the actual calving date immediately when a calving happens, as the actual caving date may differ up to 2 weeks from the expected date. The herd owners have according to the regulations for herd and animal registration up to 7 days to notify authorities about events like the birth of a calf (a calving) and culling of an animal, but most farms register the events on a daily basis. They also considered another option, namely to cooperate with the companies that offer dairy herd management systems. Two of the testbeds (Giraite and Vecauce) uses Afimilk, and a third testbed (Hof Arendse-Peters GbR) a system that exchange data with Afimilk, namely HerdePlus. Two other testbeds (Padovinio and Rudeni) use a GEA dairy herd management system. The sixth testbed (Hof Schmidt-Geel) uses QXS Milch. These dairy herd management systems generally have large market shares, they are international, and they have more or less real-time updated data of the type needed for Pitstop+, namely the cow numbers and their expected/actual calving dates, as well as animal movements. The assumption is that the companies behind these herd management systems are open for cooperation. It should be mentioned in this connection, that Pitstop+ during the testing period was extended with a new system setting that allowed the system to run in an automatic mode, which can be used for many dairy herds that has physically grouped their transition cows. Pitstop+ systems will in auto mode register any cow that starts using the system, and the system administer the supplementation of that cow until it has not been seen for 14 days, where after it is deleted from the system again. Four of the testbeds will be able to use the Pitstop+ system in auto mode after testing ends.

To test possible synergies between using Pitstop+ and HERDSMAN+ data for appointing activity-based alarms to a cow, the cows in two Pitstop+ testbeds has been equipped with Silent Herdsman neck collar-based activity measurement systems from Afimilk. Data collected by the Pitstop+ systems will be analysed in cooperation with University of Strathclyde, coordinating UC2.3, for patterns of cow behaviour that correlate to the designation of alarms in the Silent Herdsman systems.

16.3.7 Multi sensor cow monitoring (UC2.7)

The ambition of Moonsyst from Hungary is to develop an IoT based Smart Rumen Monitoring System that supports farmers in achieving more sustainable and efficient farming. Producing high-quality food with a low ecological footprint and high animal well-being is one of the greatest challenges of modern livestock production systems. In order to fulfil these requirements, farmers invest more into their properties, resulting in high-value farms and an increasing necessity to guard, track and monitor all assets with the help of innovations. Those technologies need to seamlessly and proactively integrate to turn the industry into a smart and sustainable one. While the number of connected devices continues to rise simultaneously with the growing demands on the agri-food sector, particularly precision livestock farming requires reliable, affordable, low-power, wide-range network technologies and smart sensors (LoRa and NB-IoT). As those IoT applications play an important role in this use case, leveraging their key characteristics is crucial. The system is thus made up of a small rumen bolus, monitoring various physiological data (temperature, rumen and body activity, pH level), and a cloud-based server application to provide accurate information for daily operations. At the same time, involving multiple types of farms and connected supply chain stakeholders across different regions helps to further develop and deploy the latest innovations required to perform efficient and sustainable livestock farming and animal breeding.

On the technical side the best achievement is the 6 years battery lifespan, the 800 m Lora range and the creation of a 'plug and play' system which is easy to setup and install. Of course, this needed finetuning on battery selection, capacity and energy consumption. Before the IoF2020 project, there were already 2 working prototypes of the rumen bolus, one for LoRa (design 2018 Aug) and one for NBIoT (2019 Jan). During the antenna and battery life tests, they found that used hardware component in the LoRa version cannot fulfil the requirements, but the ones used for NBIoT has all the parameters needed and can fulfil the requirements. The used sensors, LISDW12 and STS35, for NBIoT got to be the 'final' sensors we used for our LoRaWAN rumen bolus hardware. Therefore, a new hardware design was made in LoRa, the NB-IOT remained the same as it used already the finally chosen LISDW12 and STS35 sensors. Within IoF2020 for the NBIoT version only some minor changes were made on the hardware, which is changing Quectel BC68 to BC66 (same leg displacement), antenna connection optimisation, some minor change to better fit for later pin-bed programming. Also, the selection of the material for the housing of the sensor had to be solved. It all should fit in a bolus that has to operate in a quite harsh environment. The bolus technology has also a disadvantage. If the device is in the cow already, you cannot change anything, which is not always easy in a test environment.

Our initial back- and frontend technologies has been reviewed a few times. For the backend system an SQL based database was selected and modified according to the new functional specification. Also, the focus was changed from NB-IOT to LoRaWAN in the short run as NB-IOT network coverage is not sufficient so far in many countries. The communication protocols (data manipulation, compression) according to LoRaWAN requirement (and reach 6+ years battery life) were modified. Moonsyst optimised data sending and measuring intervals to minimise energy usage but maximise information. However, the architecture of the bolus remained the same, but minor update was carried out at the antenna connectors to strengthen it. Testing components were continuously made during development. Think of pH test, accelerometer test, temperature tests, range tests, consumption tests, antenna tests. For the cloud environment Moonsyst originally used Amazon AWS, but finally they moved to a cloud environment at aruba.com for the production environment. However, the test and development environment are in-house, at Akkucomp Hungary Ltd that is also one of the project partners.

Several products can be identified. An algorithm toolbox includes alert layers for direct and indirect alerts based on data coming from the bolus. An asset management toolbox handles all the boluses and cows. For the application layer 2 apps have been realised: a web-app available on request at https://mooncloud.moonsyst.com and an android application. In the test focus was on basic hardware related data like values from sensors and farm machines. In a second level this might include inputs from other services like a full weather map or a feed composition plan for example.

Testing the cow health monitoring system was done on farms in Poland and Hungary. However, it should also be applied in another country that was not covered yet in the IoF2020 project. As a start-up company it was difficult to find testbeds outside Hungary. Luckily, they have a membership at International Society of Precision Agriculture where we got a contact to Warsaw University of Life Sciences and the leader of Department of Agronomy has a Polish farmer contact. They think that the European Digital Test Farm Network can also help us to find more testbeds. They would like to modify their testbed's location. Instead of Slovakia or Czech testbeds, they were planning to have reference farms in Ireland or Sweden because they had more business opportunities in Western and Northern Europe. It is much easier to reach those farmers than the Slovakian. Of course, they do not want to give up looking for testbeds in Slovakia or Czech since it was an IoF2020 project commitment. A pre-assumption was that English communication is really common in Europe, but Moonsyst realised that lots of farmers only speak their native language, which necessitates a local partner to run the testbeds project, i.e. in Poland.

To market the system a sales and branding strategy has been developed. Part of this is building up a reseller partner network in Europe. Within the project they manage to set up the system in additional countries, such as the Netherlands and Saudi Arabia. This was also based on the experience that selling an innovative, smart product to farmers is difficult, because they do not know yet why is it is useful for them. Moonsyst sells the service, that the farmer will be able to monitor the health of all his cows in real time. This approach is stable, but we think at Moonsyst, that we should find governance connection and reseller partners, who can reach the end-users better than us.

16.4 Lessons learned

The high-level summary of the UCs within the dairy trail has provided clear evidence of the scope of the application of IoT-inspired solutions with significant potential to derive a positive impact on dairy farming sector.

- The majority of the UCs are driven by innovative companies – Qlip, Connecterra, Microfeeder (Pitstop+), Moonsyst – with an unambiguous commercial focus on business models and market development.
- The outputs of the Trial are enhanced through UCs – Grazing Monitor, Herdsman+, MELD – championed by academic groups with a drive-in cooperation and developing engineered advances in data-driven applications.

At the heart of all UCs is the sensor and thus the mechanical, electronic, wireless and power consumption characteristics of the measurement units are paramount features in their design;

- Their robustness to the on-farm operational environment and lifetimes are two of the main critical factors.
- The end-to-end system design is a strong factor of the IoT implementation technologies.
- Furthermore, the availability of Internet access is a fundamental gate to enabling a scalable and global solution; low-cost broadband provision across the rural communities remains a barrier and next generation 5G wireless networks must consider the requirements of the agricultural domain in its evolution.

Given the extended period of time required to validate the performance of the systems on-farm and more importantly to prove the return-on-investment through evidence, not all UCs reached these important goals that facilitate the ready adoption of the innovations. The cloud-based solutions are even demanding in this respect as the move to new practices within a sector that has established processes that have evolved through many years of experience is a major challenge.

The migration to more extensive data-driven applications and services is gated by overcoming the issues of data-sharing between vendors of on-farm systems.

- Automatic integration of all on-farm data is non-negotiable if further value is to be provided to the farmer and indeed the entire supply chain.
- Data ownership, sharing and monetisation remain major outstanding challenges that need leadership and policy to resolve if the sustainability and security of the food supply is to be guaranteed. This restriction has in great part limited more active collaboration between owing to disparate data formats generated by a mix of technologies.
- Although classical methods for the analysis of predominately time series have been used to create information of value to the farmer, most UCs have also applied machine learning techniques providing enriched knowledge through multiple data, limiting the reliance on complex multivariate analysis.
- The UCs have provided evidence that AI based applications are beneficial in a commercial setting, and can be the foundation for future applications utilising data integrated a cloud environment.
- The additional core processes to be integrated on the IoT platform developed to date that have not been addressed by the UCs but further release operational efficiencies are the 'operator, subscriber, management billing and support features', all required for maximum commercial impact. The focus of the UCs was confined to developing apps or web-applications to visualise the aggregated data and/or to gather feedback from users. The next phase of the evolution is not only to integrate data from on-farm operational systems but also include the optimisation of utilisation of energy, water and the management of waste. The impact of the sector on the environment is the next challenge facing the sector.

Access to appropriate farming environments is a necessity in order to develop the most impactful solutions.

- Engagement of end users is also critical to the success of not only creating a system that is readily deployed, maintained and serviced but most importantly in the development of accurate artificial intelligence algorithms.
- Capturing the knowledge of farmers of their animals and current practices informs on the features that are the foundation for the definition of appropriate algorithms and coupled to the ready access of data, especially truthing data, are core lessons learned.
- The test of the solutions on representative farms from each UCs provided consistent evidence to corroborate the need.
- Careful planning in collaboration with farmers to ensure the validation phase is aligned with the goal through agreed key performance indicators is essential to the adoption of the solution.
- The UCs re-established new partnerships if the level of engagement with the original farmers had diminished. Continual direct feedback from the end user is required to progress to a commercial offering from proof-of-concept to a viable product.

The goal of the IoF2020 project to stimulate development and demonstrate the value of IoT based solutions in the domain of agriculture and food production chains through establishing a co-creation environment has been delivered in great part.

- The UCs comprising the Dairy Trial provided evidence in support of the conclusion for the particular segment of the overall sector with industrial partners driving developments in close harmony with end users.

The IoF2020 project structured the eco-system so as to enhance the outputs of each trial through exchanges of knowledge between Trials.

- Regular exchanges of knowledge and experiences within the dairy trial were supplemented with opportunities to understand the relevant technology developments in other Trials/UCs.
- The value of the latter series of meetings was principally in the information provided, but given the limits in resources did not result in extended cooperation between UCs in the multiple domains.
- Annual meetings where also beneficial to sharing of experiences from other trials.
- The objective to create global impact and forge international collaborations although facilitated by the main project management group, was largely delegated to the individual UCs.

The main project work streams were established with expert knowledge on technology, business and eco-system themes.

- The pools of expertise supported all UCs to resolve challenges in a timely manner and set stretched goals dependent on progress. An example is the STRIDE analysis task to identify risks of cyber breaches of solutions directly connected to the Internet, a stimulus to considering these issues at the outset of and throughout the system design. Although a reticence to undertake the analysis was apparent at the outset, with time and further understand, the majority of UCs derived notable benefit from the task.
- The evolving targets set throughout the project highlighted the comprehensive feature set expected of a commercial solution.
- The second role of the theme experts was to capture impacts and experiences from UCs in order to surface trends and insights, as a seed to prioritise goals and influence policy e.g. input to the creation of standards for the sector.

The participation within the IoF2020 consortium has brought significant benefit for commercial partners.

- Similar to other large scale multi-institution projects, the overhead in terms of reporting and general administration although a significant is outweighed by the benefits derived from the exchange of ideas, best practice and sector understanding from experts in relevant domains.
- The eco-system established by IoF2020 has accelerated innovation in a key industrial sector and laid the foundation for a series of Hubs across Europe that continue supporting the community to meet the ever-increasing demands for high quality, safe produce being placed by a growing global population. However, in the end to be successful as use case you have to make your own choices. The project and Hub environment should help you in achieving your own goals.

Acknowledgements

The IoF2020 project was funded by the European Union. This chapter is written with the support of the following Dairy Trial members: Stephanie Van Weyenberg, Evi Lippens and Jarissa Maselyne (ILVO), Laurence Claeys (Sensolus), Niels Molenaar and Niels Rutten (Connecterra), Ivan Andonovic, Craig Michie, Andrew Hamilton and Christopher Davison (University of Strathclyde), Arjan Bom and Floris Ruiterkamp (Qlip), Paul Malone (WIT), Henning Lyngsø Foged (Organe Institute), Péter Gesler and Márton Rajnai (Moonsyst), and Henrieke Otte (365FarmNet).

The presented work is original, there is no conflict of interest and project activities met ethical and legal requirements since this work is part of the IoF2020 project and all partners signed the consortium agreement.

References

Animal Task Force (ATF), 2016. A strategic research and innovation agenda for a sustainable livestock sector in Europe. Suggested priorities for research for Horizon2020 2018-2020 Work Programme to enhance innovation and sustainability in the livestock production sector of Europe's food supply chains. Second White Paper of the Animal Task Force, Brussels, Belgium.

Animal Task Force (ATF), 2021. A strategic research and innovation agenda for a sustainable livestock sector in Europe. Suggested priorities for research for Horizon Europe to enhance innovation and sustainability in the livestock production sector of Europe's food supply chains. Third White Paper of the Animal Task Force, Brussels, Belgium.

Hassan, Z., Ali, H. and Badawy, M., 2015. Internet of Things (IoT): definitions, challenges, and recent research directions. International Journal of Computer Applications 128: 975-8887.

IOF2020, 2020. Dairy. Available at: https://www.iof2020.eu/use-case-catalogue/dairy

Lokhorst, C., 2018. An introduction to smart dairy farming. Van Hall Larenstein University of Applied Sciences, Leeuwarden, the Netherlands, 108 pp. https://doi.org/10.31715/20181