Improving Resources Efficiency of Agribusiness Supply Chains by Minimising Waste Using Internet of Things Sensors (REAMIT)

# Deliverable 3.3: Report on the pilot test and development of the sensor prototypes (Story Telling)

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# 1 Introduction and objectives

The Pilot Test Storytelling is a document developed for each REAMIT pilot test while the pilot test is being implemented. The aim of this descriptive document is to capture detailed information and experiences of the REAMIT team during the implementation of the pilot test. Capturing nuanced information from online meetings with REAMIT team and pilot test companies aims to avoid losing valuable and nuanced information. Content of this document may be helpful for REAMIT publications in the future.

# 2 Dutch Pilot: PICNIC

## 2.1 Presentation of Picnic

Picnic was founded in the Netherlands in 2015 and started with 4 delivery vans. In 2022 more than 1,000 electrical vans drive around in about 120 Dutch cities. With hundreds of thousands of customers and a monthly expansion to new cities, Picnic was named the fastest growing company in the Netherlands in 2019. Picnic thinks grocery shopping can be done differently: faster, easier and cheaper.

The idea is simple. Picnic arranges the groceries, so that you have more time for more fun things. At Picnic you can order all your groceries online within a few minutes. And all this for the lowest price and free home delivery. All groceries are delivered directly to the customers home, without expensive shops in expensive locations.

Picnic has an end-to-end business and a just-in-time supply chain. Picnic has a data-driven approach and an app-only store. Technology, smart planning, and a fleet of electric vehicles lead to less food waste and fewer food miles.


*Figure 1 Unloading of Picnic's E-truck*

## 2.2 Recruitment

In the beginning of the REAMIT project, when the team started looking for pilot partners, Marcel Steegh from Whysor thought Picnic would be a good company for pilot testing. He called Picnic and was redirected to Frank Gorte, who was then working on Innovations at Picnic Technologies. After that, Marcel visited the Picnic fulfilment centre in Amsterdam in January 2020 and together they came up with a plan for a pilot test at Picnic.

## 2.3 Challenges in food waste

Because Picnic is a data driven company and has a temperature controlled and conditioned supply chain and a (not cooled) last mile delivery system with routes of maximum 2 hours, they experience very little food loss. Their challenges lay mostly in the loss of energy when too many icepacks are being used for example when cool boxes are at the beginning of a delivery route. Food loss, based upon complaints of customers, like bruised fruits or broken eggs, may be assigned to inappropriate box-handling (falling or bumping) or rough driving of the last-mile-delivery (e.g. speeding on bumps in the road).

Based on the Picnic data driven weather regime, Picnic decides daily how many icepacks (between 2 and 5) are added to every box that contains refrigerated items and how much dry ice is added to every box that contains frozen items. Picnic wants REAMIT to prepare a personalized cooling profile per box, using data from a.o. the Picnic weather regime, the duration of travel, such as shipment from Picnic regional fulfilment centre to Picnic local hub and the duration of the last mile delivery of every box. Picnic is looking for a system which will perform the following:

1. The boxes should be connected to the cloud to allow for (near) real-time data reporting / monitoring while the boxes are being transported.
2. The sensor housing should be able to withstand forces of heavy groceries and differences in temperature and humidity.
3. Development of a personalized cooling profile per box, based upon outside weather conditions combined with the difference in temperature inside the cooling box during transport.
4. Analysis of data regarding xyz/acceleration of the box (shock detection).
5. The power consumption of the proposed system should be such that maintaining the equipment does not become an arduous task.

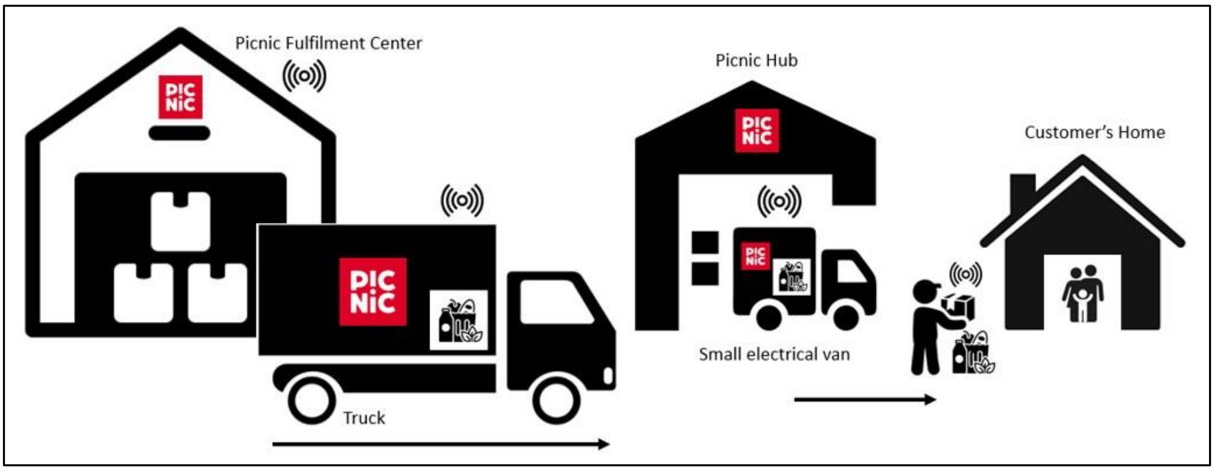



*Figure 2 – Picnic's supply chain*

## 2.4 The selection of relevant sensors

The REAMIT team at Whysor (the Netherlands) examined Picnic's system requirements and proposed a real-time monitoring and alerting system for anomaly detection during the transport of the groceries.

The system needed to allow real time data upload while the sensors were moving in trucks.

Sensors with LoRaWan connectivity were selected because the field of operations for this pilot was in the Netherlands, where a covering LoRaWan network is provided by KPN.

For the Picnic pilot, the Temperature/ Relative Humidity sensor that was selected can monitor in both ambient and chilled zones of trucks and warehouses.

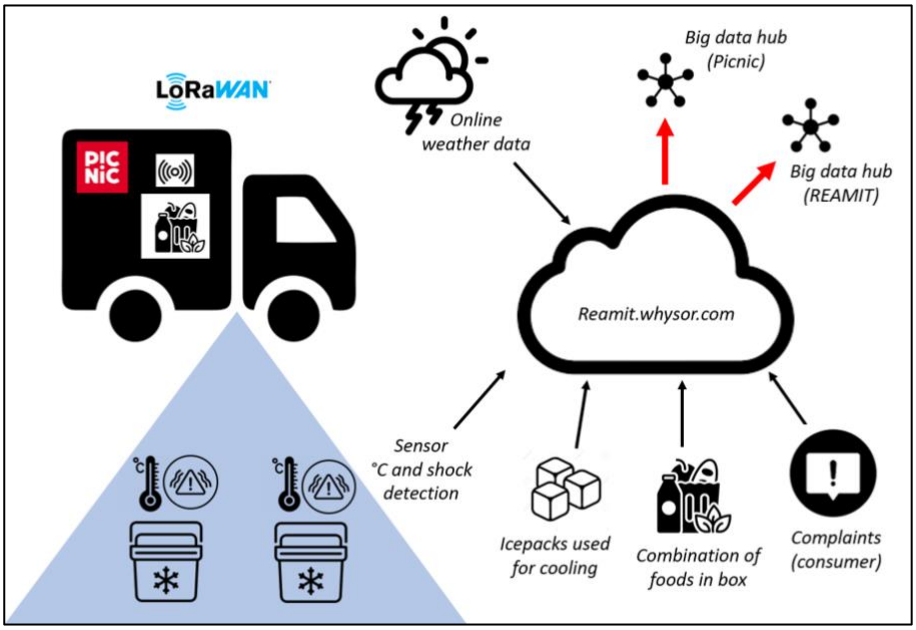



Figure 3 Proposed IoT solution

A solution was found with Elsys (Sweden), who had created an indoor LoRaWan room sensor (EMS) for measuring the indoor environment. With its small size and minimalistic design this sensor is perfect for use in smaller spaces, like a cooling box.

Inside EMS you will find internal sensors for measuring indoor temperature, humidity, acceleration, opening activity, and a water leak detector. The EMS is slightly larger than an AA-battery and runs on 1 x 3.6 V AA Lithium battery, with an expected battery life of up to 10 years (depending on configuration and environment).

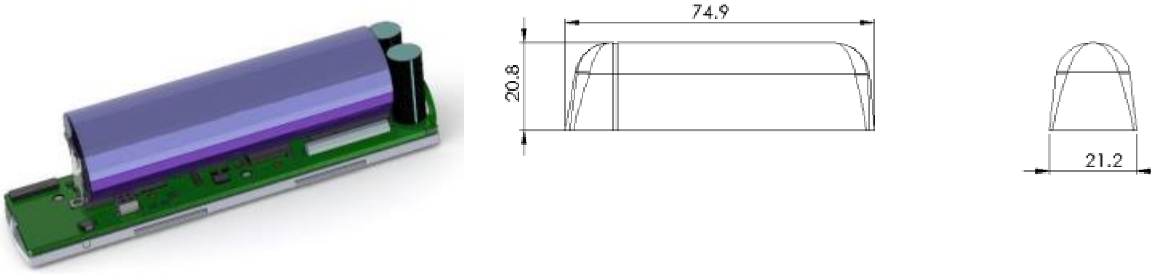



Figure 4 Elsys EMS sensor

Elsys is a known supplier to Whysor. Additionally, Whysor already had good experiences with the sensor for similar use cases over the last years.

## 2.5 Installation and implementation of the sensors

In June 2020, Whysor asked the University of Bedfordshire to purchase 20 EMS sensors. Because this was the first procurement process, and a lot of questions arose from the procurement department at BED, the process was lengthy.

In September 2020 the sensors were delivered at Whysor in the Netherlands.

To install the correct software Whysor needed a connector. The connector that was delivered with the sensors didn't fit and a new one needed to be ordered.
After receiving the correct connector and installing the software, the sensor still didn't work as it should. Several contacts were necessary between Whysor's lead developer and the manufacturer.

This process was ready in October 2020.

In November 2020 2 sensors were sent to Picnic to be installed inside two coolboxes for testing and validation of shock detection. Due to the 2nd COVID-19 lockdown in the Netherlands and the Christmas holidays the sensors were installed in January 2021.

After this first testing period, we noticed that the firmware of the sensor didn't provide the correct data for shock detection for the purpose of our research.

Manufacturer Elsys was contacted in February 2021 regarding this problem and reacted as follows:

*The accelerometer isn't in itself capable of register shock stand alone. The possible way we have to make something close to what you need would be to set the microcontroller awake on movement so it can sample acceleration continuously. When the uC is awake the current consumption is very high, so it would need a trigger level on movement that is pretty high, and then go back to sleep after a set amount of time until next trigger event.*

This adjustment needed to be done by a firmware update. Elsys promised to do a few simple tests with custom software to see if it is possible to wake and sample. In March 2023 they reported back that the feature was harder than they initially thought and were planning to implement the feature in their next firmware release.

In August 2021, Elsys reported back that they were late on development, due to unexpected demands for their sensors. The new version of firmware was being worked on at that time, but not ready for release.

Whysor kept on trying to contact Elsys several times between August 2021 and April 2022, but they never reported back on the firmware release.

In the meantime (May 2021) Whysor and Picnic decided to start testing with the sensors as they were, with measurements on temperature.

In July 2021 Whysor visited the Picnic fulfilment centre in Apeldoorn (the Netherlands) and installed 4 sensors in 2 different cool boxes in order to define:

- What is the best position for the sensor: on the bottom or at the top.
- What is the best way to stick the sensors (hard plastic) to the box (styrofoam). We tried two different types of glue: manufacturer's double-sided tape and special flexible adhesive sealant.

Figure 5 - Groceries in a cooling box

Figure 6 - Installing the sensors in a box

ot test and de (Story Telling).

After this testing period we defined that the best position for the sensor is on the bottom of the cool box and the best adhesive is special flexible adhesive sealant.

In September 2021 16 more sensors were installed inside the boxes. The sensor data came in fine and was sent to partners in data-analysis. However, in a few weeks' time, we noticed that less and less sensors were connected. We evaluated with Picnic and defined that the sensor housing was not sustainable enough and broke when heavy groceries were put on top or bumped to the housing. All sensors but 1 had broken down at that point.

As a solution Whysor built a prototype of 2 flexible rings, printed by a 3D-printer to protect the sensor housing.

*Figure 7 - The prototype with 2 flexible rings*

In October 2021 20 new sensors were purchased by BED and were delivered to Whysor in November 2021. In November 2021 the 3D-printed flexible rings were delivered to Whysor. In December 2021 the 1st batch of 10 sensors were assembled with the 3D-printed flexible rings and delivered to Picnic for self-installation (due to lockdown in the Netherlands) with online guidance from Whysor. In December 2021 Whysor had a meeting with Picnic to discuss the required additional data Picnic wanted to deliver for research purposes and data analysis of the data by the REAMIT-team.

Between January and March 2022, we noticed that the 10 sensors that were installed were breaking down one after another. In March 2022 only 3 sensors were still working. Whysor met with Picnic in March 2022 and discussed the breaking down of sensors, the data requirements for further research and the installation of the 2nd batch of 10 sensors.

In May 2022 Picnic reported back to us and Whysor decided to the next regarding the experienced problems with the sustainability of the housing of the sensors. There were two issues:

- Because the sensors are placed in a cool box made of styropor, an adhesive needed to be used suitable for both hard plastic and styropor. We also want to be able to change the battery of the sensor when needed, so we can't just kit the whole sensor to the cool box. Picnic agreed to send a (part of a) cool box, so Whysor can do some tests what adhesive to use.
- The sensor housing appears to be not suitable for use with heavy groceries on top. The first batch of sensors got broken in a period of weeks. Whysor designed a 3D-printed protective ring for the sensor housing. With this ring the sensor was better protected, but still broke down over a longer period. Whysor did not receive proper feedback why the sensors broke down

early 2022. It is Whysor's assumption that the sensors broke down again due to heavy groceries. There were still 10 sensors left that are planned to be installed with 3 instead of 2 protective rings.

Whysor received an Excel-file with the trip details data Picnic wanted to share with the REAMIT team without having to sign an NDA-agreement.

In August 2022 Whysor developed a new, stronger and flexible housing to protect the sensors to the large force of the groceries. We 3D printed the new housing for the remaining 10 sensors.

*Figure 8 - 3D printed new housing*

The analytics team started with the first analysis of the sensors data and in November REAMIT-partner SenX was defined as the first contact person for the analysis of data from Picnic.

Between September and December 2022 Whysor tried to contact Picnic for installation of the 2nd batch of sensors with new housing. Picnic was non-responsive for quite some time.

At the end of December 2022 Whysor was able to contact Frank Vollering from Picnic and discussed the following:

- Testing with 10 new sensors, with adapted housing, for a few more weeks, especially on the durability of these sensors. Frank indicated that he needs to discuss this internally with the relevant colleague.
- From the data we already have from the earlier batch of sensors, we want to select some trips, from which we will get the additional data from Picnic. Imke has asked Jean-Charles to determine these trips.

In January 2023, Ulster University has reached out to Picnic for the qualitative interview. Picnic has not responded to that.

Frank Vollering became ill in the beginning of 2023 and has not been able to report back to Whysor on the above *(situation end March 2023)*.

SenX and Whysor have defined a number of trips for which we would like to receive additional data to analyse.

Because the project is coming to an end, the REAMIT-team decided to no longer focus on the data-analysis of this pilot. If there will be any contact with Picnic in the last weeks of the project, Whysor will ask them what they still would like to accomplish with the REAMIT-team.

## 2.6 Relationship with the company through the pilot test

First contacts with pilot partner Picnic for the REAMIT project were between Whysor and Frank Gorte, who worked on Innovation at Picnic Technologies. He also attended one of the RSC/WP/RAC meetings online to present the company to the REAMIT team.

After Frank moved to another department our first contact was Thom Groothuis, who was operational supervisor at Picnic technologies. Thom worked with Whysor on installing sensors for the first, second and third testing round and gave the Whysor team a tour at the Picnic Fulfilment Centre in Apeldoorn, the Netherlands. After Thom got a promoted and moved to another fulfilment centre, our first contact became Frank Vollering, who is a business analyst at Picnic.

Overall Picnic was one of the first pilot tests of the REAMIT project. Several reasons have made communication between the REAMIT-team at Whysor and Picnic slow: Covid-19 made the company focus on their primary business and not on research activities; lengthy procurement process of the sensors; slow reactions between the two companies, initial reluctance to share data with the REAMIT project team, etc.

At the end of the pilot testing period (March 2023) we have not yet started the 4$^{th}$ round of testing, due to health issues of our first contact at REAMIT and the lack of priority for the REAMIT project at Picnic.

## 2.7 Communication and dissemination activities

Several newsletter items have been written about the pilot at Picnic. A poster has been created and Whysor has talked about the REAMIT pilot at Picnic at all of the REAMIT symposia. University of Essex is developing a case study.

## 2.8 Other best practices and lessons learned

### 2.8.1 Recommendations

Protecting the sensor when the boxes are filled with groceries, has appeared to be challenging, due to the frequency of handling and the impact of heavy groceries.

The tracing of sensors that are not working needs more research because of the complexity of the Picnic box routing method.

Commercial companies' priority is to run their business. They have little time for research.

### 2.8.2 Good practice

The technical specifications of the sensors meet the expectations of Picnic. The sensor responds well to changes in temperature and has a stable signal during all phases of the transport.

# 3 Luxembourg Pilot: BIOGROS

## 3.1 Presentation of BIOGROS

Biogros is a wholesaler for high quality organic and biodynamic foods (3.500 items in fruit, vegetables, dry goods and dairy produce) in Luxembourg.
For more than 25 years, Biogros has been supplying high quality organic food six days a week to their Luxembourg customers.

Biogros stocks products from well-known organic brands like Naturata, Rapunzel and Lebensbaum, as well as organic products from lesser known or smaller producers. Thanks to their close collaboration with organic farmers from the cooperative Bio-Bauere-Genossenschaft Lëtzebuerg (BIOG), they also offer a whole range of regional organic products.

*Figure 9 Overview of Biogros' activities*

## 3.2 Recruitment

In February 2021 our project lead, prof. Ram Ramanathan, had a meeting with Nicole Skirde-Vural who is the contact point for Interreg North-West Europe in Luxembourg. She identified Biogros as a possible pilot partner for the REAMIT project and contacted Patrick Kolbusch, the CEO of Biogros.

## 3.3 Challenges in food waste

Biogros is a company with a complete supply chain. For example, fresh vegetables like celery, lettuce and mushrooms, produced by organic farmers from the cooperative Bio-Bauere-Genossenschaft Lëtzebuerg (BIOG) are transported from the farmer to the Biogros warehouse by Biogros trucks. In the warehouse the vegetables are packaged and then transported to the retail outlet, gastronomy business, large-scale kitchen or small village shop, that ordered the fresh vegetables.


*Figure 10 Supply chain at Biogros*

While receiving deliveries from BIOG organic growers in Luxembourg, Biogros noticed that the quality of fragile produce, such as mushrooms, unions, potatoes and celery roots, would occasionally not be up to standard. Biogros wants to gain insight in the climatic conditions (temperature and humidity) in the full supply chain, from grower to supermarket.

## 3.4 The selection of relevant sensors

### 3.4.1 Logger

*Digital Matter Eagle logger*

REAMIT needed to find a solution which would allow real time data upload while the sensors were moving in trucks. Since Whysor was not familiar with the cellular infrastructure in Luxembourg, we spent two months testing connectivity at different locations and while on the move in Luxembourg. We chose loggers with cellular connectivity because these loggers also include the feature of detecting whether a truck is moving or stationary (trip-detection). For this pilot trip-detection is important regarding the following challenges:
First it enables to only alarm when the trucks are in use. Second it enables to measure and send data with a lesser frequency when the trucks are not in a trip, resulting in a much longer battery life.

A solution was found with Digital Matter (South Africa), who had created a cellular logger device. This logger contains its own sim card and uploads data to the cloud using a 4G connection, much like a mobile phone. Digital Matter offer both a Falcon and Eagle device. For this pilot, the Eagle was selected which, while heavier, offers a longer battery life. The Eagle logger is customisable and contains I2C, RS232, SPI, and One-Wire communication buses allowing for a range of sensors to be configured to best suit the needs of the application.

Technical datasheet Eagle

*Figure 11 Digital Matter Eagle logger*

### 3.4.2 Temperature and Humidity sensor

*Amphenol Advanced sensors, Temperature and Humidity sensor T9602-3-D*

Biogros wanted to be able to monitor both temperature and humidity in trucks and in warehouses. For this, we selected the 1.8m T9602 T/RH I2C probe by Amphenol (USA), because it was the only low-power temperature and humidity sensor that is currently in stock, due to the worldwide chip-shortage. Additionally, Whysor already had good experiences with the sensor for other use cases over the last months.

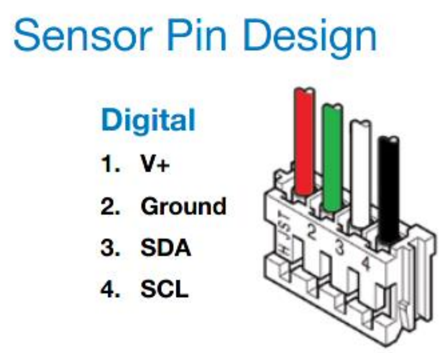
Technical datasheet

*Figure 12 Amphenol Advanced Temperature and Humidity sensor*

*Figure 13 Total hardware set-up*

## 3.5 Experience fixing sensors

To connect the Temperature and Humidity sensor T9602-3-D to the Eagle logger's screw terminal the connector they come with has to be removed. The colour mapping of the wires is shown in the following picture:




The Eagle logger supports the function of trip detection based on data from an accelerometer and GPS. When a trip starts, the accelerometer first detects the movement. Afterwards the GPS is used to detect if it was just a random movement or if the logger changes its location. Then the device will be in "trip" mode until the GPS detects that the logger is stationary for a certain configurable timespan. The logger then reports the trip status alongside other digital inputs which can then be decoded using bitmasks.

The device will stay in a low power mode until the accelerometer detects a movement. Then the device will get a GPS fix for a certain amount of time to check if there is movement, if yes it will start a trip. Once in a trip the GPS coordinates are queried on a given interval. If there is no movement for a given period, it will end the trip.

As you see there are many configuration values involved. For example, the value in meters can be set for when a trip should be started or the force needed to trigger the accelerometer. For now, I set everything to default values specified by the manufacturer.

One of the most important things - especially in regard to the battery lifetime - is to set the sending period. Currently it is set to measuring and sending every five minutes. This will result in a short battery lifetime. We can set the device to individual values for measuring and sending for both states - when in a trip or out of a trip. You could set for example - when out of a trip measure every twenty minutes and send the values every twelve hours - when in a trip measure and send every five minutes.

The sensor was mostly plug-and-play, because the integration of the sensor was already done by the start of the pilot, due to previous experience of Whysor with this sensor in another project.

### 3.6 Installation and implementation of the sensors

In November 2021 two sensor units (with logger “Falcon”) were sent to Biogros by Whysor to test the connectivity in Luxembourg inside the warehouse, the trucks and at three growers. In January 2022 the connectivity tests had been completed.

In December 2021 Whysor reported to the REAMIT team that due to a worldwide shortage of microprocessors (computer chips), the production of the loggers that were used in the pilot testing of technologies at Human Milk Foundation, Biogros and Musgrave, was affected.

Whysor contacted the manufacturer of the loggers, Digital Matter, and they informed us that the Falcon logger that was used at Biogros was out of stock and would not be available until at least February or March 2022 (no guarantees on the delivery in these months).

As the REAMIT team was was still in the process of testing connectivity at Biogros and Musgrave, HMF had already asked for 12 additional sensors. The (Eagle) logger we could use is a larger version which has more options and is a bit more expensive (larger means twice the size of the current logger). Digital Matter had at that point still 40 of these Eagle loggers in stock and after that there would be no stock left and due to the shortage of microprocessors, would not be for some time.

Whysor advised the REAMIT-team to instantly buy these 40 loggers and proceed with the pilot tests with this new logger.

In January 2022 15 loggers “Eagle” and 15 RV/T sensors were purchased for the pilot test at Biogros by the University of Bedfordshire and were self-installed by a Biogros’ technician in March 2022 in different departments inside the Biogros warehouse and inside 9 trucks. In July 2022 3 more sensor units were installed by Whysor inside the warehouses of three BIOG farmers’ warehouses.

*Figure 14 Sensors installed in Biogros warehouse and trucks*

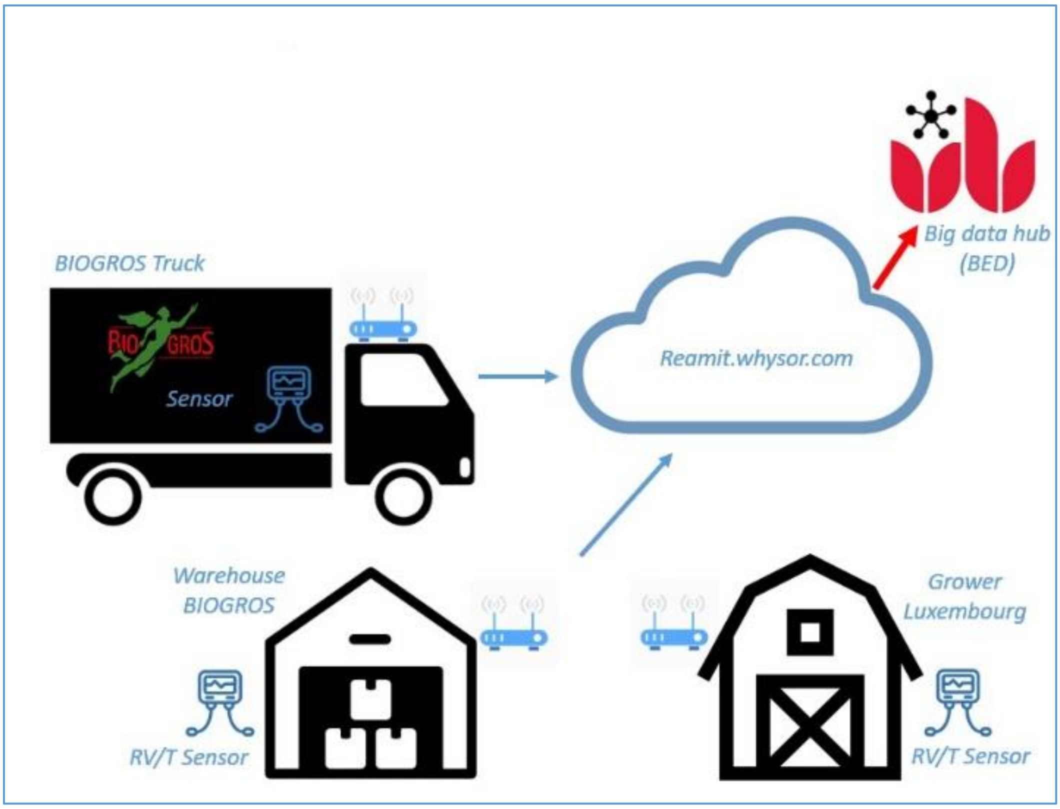



*Figure 15 - Proposed IoT solution*

In April 2022, we have created different dashboards for the Biogros pilot. So that the data that is collected by the sensors is also visible. We created 5 different dashboards to keep everything as clear as possible; there is a dashboard for the trucks, for the Biogros warehouse and every farmer has it's own dashboard.

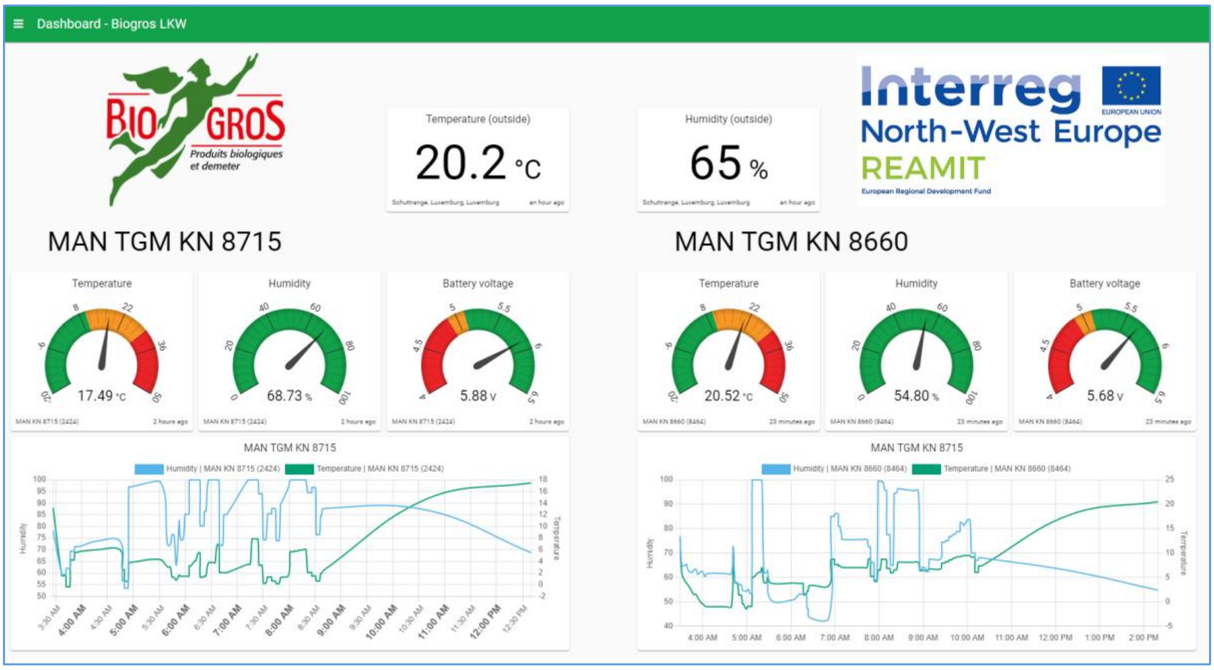
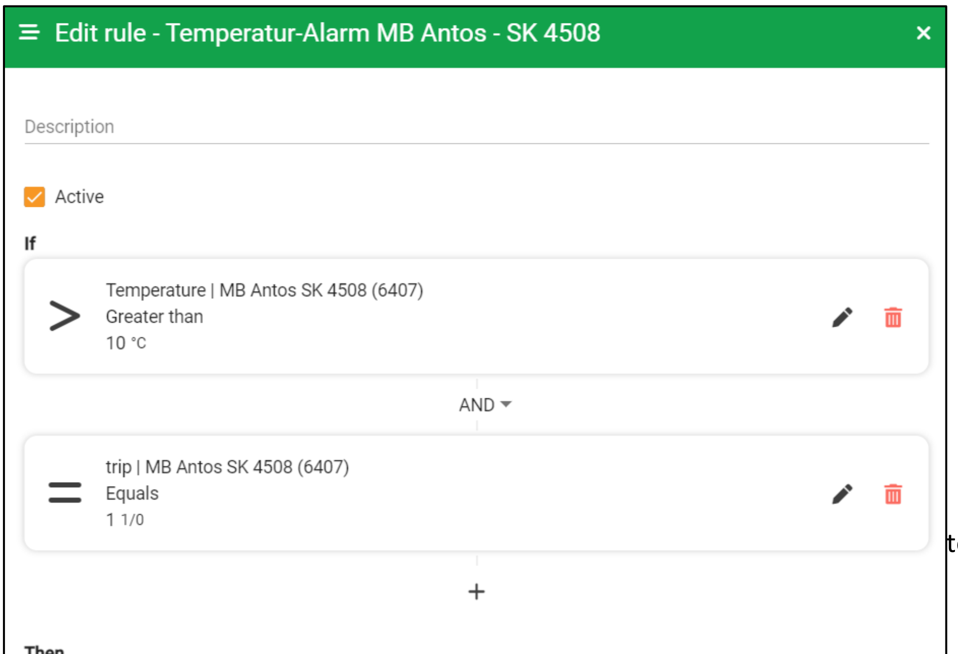



*Figure 16 - Screenshot of a part of the Biogros REAMIT dashboard*

In September 2022 we added alerts (rules) to the dashboard for the warehouses and trucks. That way, an email is sent to Marco Klinkerfuss, our contact at Biogros, when the temperature gets too high in a truck or in the warehouses. For the trucks that's when the temperature is above 10 degrees for half an hour. And for the warehouse an email will be send, after one measurement, when the temperature is above 8, 10 or 12 degrees (depending on the sensor).

In October 2022, we received a message from Marco Klinkerfuss that he was receiving too many alerts from the trucks. This was because a truck is not cooled when not in use which caused the alerts to go off too often. We then added trip detection as an additional condition, which ensures that the truck must be moving as well as above 10 degrees before an alert is sent. This solved the problem.

The REAMIT-analytics team started an analysing the data received by the sensors installed at Biogros. REAMIT-partner SenX was the lead in the analysis of data and developed an anomaly prediction model which will be presented to Biogros before the end of the project.




totypes (Story Telling).

## 3.7 Relationship with the company through the pilot test

From the beginning of the project's launch, Whysor contacted Biogros' owner Patrick Kohlbusch and sales manager Christelle Nicolay. In May 2021 Whysor visited Biogros for a meeting with Patrick, Christelle and Roland Henkes, the technician of Biogros and received a full tour of the warehouse.

In January 2022, Christelle Nicolay joined the online RSC/RAC meeting for presenting the company to the REAMIT team. In April 2022 Roland Henkes left Biogros and Christelle Nicolay left in May 2022. The first contact person became Marco Klinkerfuss, a technician.

During the project, there was good mutual contact between the REAMIT-team and Biogros with some regularity.

## 3.8 Communication and dissemination activities

Several newsletter items have been written about the pilot at Biogros. A poster has been created and Whysor has talked about the REAMIT pilot at Biogros at all of the REAMIT symposia.

In July 2022 some members of the REAMIT team visited Biogros to conduct interviews and film their operations for the REAMIT Documentary video.

In March 2023, Marco Klinkerfuss was interviewed by the University of Ulster for a qualitative interview.
A case study about Biogros was developed by Nottingham Trent University with assistance of Whysor.

## 3.9 Other best practices and lessons learned

After installation the batteries went empty really quickly. Because default settings of the sensors were set to measure and send data every 5 minutes, the batteries of the sensors had gone empty in a short time. Default settings of sensors are set to send data every 5 minutes, to be able to test whether the sensors are reporting to the connected dashboard, directly after installation, without the installer having to wait for a long waiting time for the first data to be send and received. When Biogros defined how often they wanted to measure and receive data, we altered the settings for the sensors inside the warehouse to measuring every 2 hours and sending data every 4 hours. This extended the lifetime of the batteries from 2 months to approximately 8 months.

We recommend that sensor settings are adjusted soon after installation, to save battery life time.

On a Sunday in the beginning of 2023 Biogros received a notification of their own operating system that their cooling system was failing. Normally, in weekends, the operating system would also send a notification to an external service company, hired to resolve malfunctions outside the working hours of the Biogros employees.

In the evening the technician of Biogros received an alert notification of the REAMIT system in his e-mail, telling him there was an anomaly detected in the temperature of the warehouse. Because of the alert, the technician drove to the Biogros' warehouse on Sunday evening and discovered the system failed to send the notification to the external service company and the problem of the cooling system had not been resolved during the day. Due to the alert sent by the REAMIT system, there was no loss of fresh food products and the problem of the failing cooling system was resolved in time.

# 4 Northern Irish Pilot: Musgrave

## 4.1 REAMIT Pilot Test Storytelling: Musgrave (NI)

Musgrave Group Ltd. is an Irish food wholesaler, founded in Cork by the Musgrave brothers, Thomas and Stuart in 1876. It is currently Ireland's largest grocery distributor, with operations in Ireland and Spain, and estimated annual sales of over €4 billion. They estimate that they are responsible for feeding 1 in 3 people in Ireland through 11 leading food and beverage brands whom they supply groceries to. They employ approximately 250 employees and operate from 10 warehouse locations in Ireland. The company is still largely owned by the Musgrave family. Musgrave Northern Ireland, a subsidiary of Musgrave Group, has warehouses in Belfast, Lurgan, and Derry and is headquartered in Belfast, Northern Ireland.

## 4.2 Recruitment

Trevor Cadden, Professor in Supply Chain Management had previously worked with Musgrave on other research projects and organised a meeting to present the REAMIT project to the company in May 2021. Musgrave were very interested in the project and agreed to participate after the first pitch meeting.

## 4.3 Food waste issues at Musgrave

Robert Gallagher, Warehouse & Transport Operations Manager at Musgrave recognised that on occasion, while performing deliveries to their business customers, the refrigeration units in the delivery vans operating in the greater Belfast area would break down, without any indication to either the driver or the logistics staff at the warehouse. The temperature in van carrying chill and frozen products would increase, surpassing the food storage temperature safety threshold, resulting in a van load of spoiled stock. It was estimated that out of their fleet of 5 delivery vans, at least one would suffer refrigeration problems over the course of a year. Musgrave sought a system which would perform the following:

- The vans should be connected to the cloud to allow for real-time data reporting / monitoring while the vans perform deliveries.
- The vans have both a chill and a freeze zone, both of which should be monitored throughout a journey.
- An alerting system should send SMS messages to drivers and warehouse logistics staff notifying if any anomalies occur.
- Alerts should not be sent when the van is stationary e.g., parked overnight, performing a delivery, etc.
- The power consumption of the proposed system should be such that maintaining the equipment does not become an arduous task.


## 4.4 Selection and configuring of sensors

REAMIT needed to find a solution which would allow real time data upload while the sensors were moving in the vans, but since Musgrave is based in the UK there was no LoRaWAN network present.

Initially Bluetooth Low Energy (BLE) temperature and humidity sensors were proposed and investigated for the pilot test, which would connect to the driver's mobile phone when they entered the van, and record and upload the data to the cloud using the phones cellular connection. However, deploying these sensors would have meant developing a bespoke android app from scratch, which, upon investigation, was considered a non-trivial task. This implementation of the continuous monitoring system was therefore deemed outside of the scope of the project.

An alternative solution was found with Digital Matter (South Africa), who had created a cellular logger device. This logger contains its own sim card and uploads data to the cloud using a 4G connection, much like a mobile phone. Digital Matter offer both a Falcon and Eagle device. For this pilot, the Eagle was selected which, while heavier, offers a longer battery life. The Eagle logger is customisable and contains I2C, RS232, SPI, and One-Wire communication buses allowing for a range of sensors to be configured to best suit the needs of the application.

Musgrave wanted to be able to monitor both the freeze and chill zones of their vans, so we had to configure the loggers with two separate temperature probes. Digital Matter produce their own I2C temperature probe which would allow support for two sensors wired into the same channel, however these were unfortunately out of stock. I2C devices produced by other manufacturers could not be configured with custom addresses and thus the I2C bus would only be able to support one sensor. For this, we selected the 1.8m T9602 T/RH I2C probe by Amphenol (USA). For the second temperature probe to monitor the chill zone, we selected the 3m DS18B20 by Maxim Integrated (USA) which used the One-Wire communication bus.

*Figure 18: DS18B20 Temperature probe, T9602 Temperature and Humidity probe, Pololou 2119 voltage regulator*

One caveat of selecting the DS18B20 on a cable run >2m is that it needed a 5v supply due to voltage drop on the longer cable. Unfortunately, the Eagle logger only had a 3.3V supply so a voltage regulator had to be added to the circuit, which would step up the 3.3V to 5V. The Pololou 2119 was selected and added to each of the DS18B20 probes.

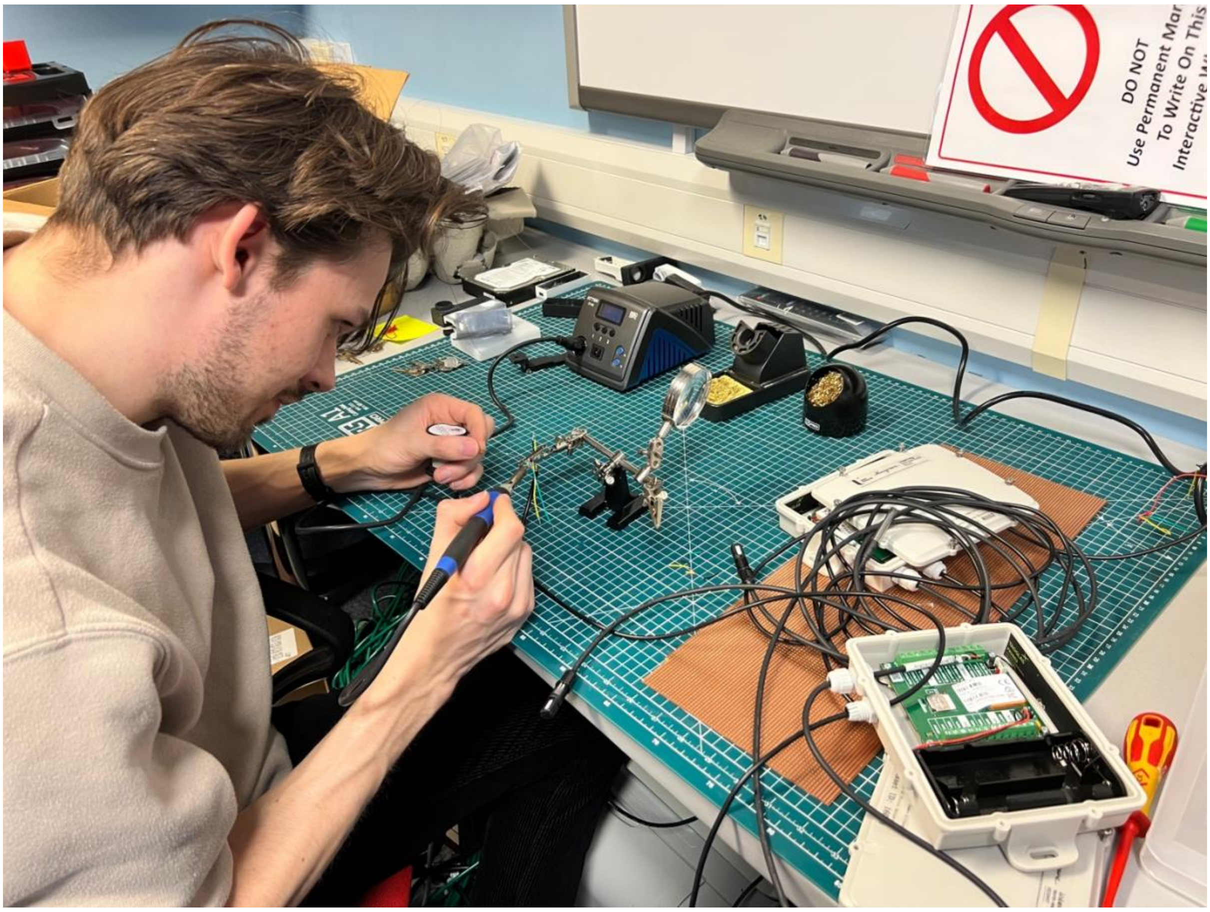



*Figure 19: Adding the Pololou voltage regulator to the DS18B20*

## 4.5 Installation of sensors

The sensor order was placed as part of a larger order from Whysor with Digital Matter on 17 December 2021. The larger order was first shipped to Whysor (NL) and then the 5 loggers for Musgrave were repackaged and sent on to Ulster. These arrived at Ulster U niversity on 9 February 2022. Wiring the loggers, adding the voltage regulator, and completing work on the trip detection algorithm took approximately 2 months. The sensor setups were completed by James at Ulster by 19th April 2022 and 3 were installed in Musgraves Vans on 23 April 2022.

To reduce the invasiveness of the installation, cable ties were used as the mounting method of the loggers within each of the vans (see figure 3). The logger was attached to the dividing wall between the freeze and chill zone of each van with cable tie, using a conveniently located mounting point approximately halfway up the wall. The sensors were positioned in the desired location using adhesive cable-tie bases (figure 4) and cable ties. This ensured the cables were kept out of the way of stock loading / unloading performed by Musgrave so that the additional equipment now located in the vans did not have an impact on warehouse and logistic productivity.

*Figure 20: Initial freeze-zone sensor position on roof of van (left), and right, mounting location and method of the IoT logger.*


*Figure 21: Self-adhesive cable tie base to allow sensor probes to be placed in the correct position of the freeze and chill zones of the vans. Cable ties pass through this mounting point to secure cables to the desired location.*

## 4.6 Implementation of sensors

Sensors were installed in their fleet of 3 vans serving the Belfast area, allowing staff to monitor the temperature of the vans every 5 minutes using the Whysor dashboard. Automatic text alerts would be sent to the logistics warehouse staff when the temperature rose above a defined threshold limit during a delivery. This would allow the logistics staff to alert the drivers of the issue and redirect the food back to the warehouse before it became spoiled.

Ulster worked on developing the trip-detection algorithm with partners' Whysor and sensor supplier Digital Matter. This algorithm would ensure text alerts were only sent when the vehicle was being driven (and not when parked overnight), as well as significantly improving the battery life of the sensors. Using an accelerometer, the algorithm put the device to sleep when not in use. Data upload and recording would be restricted to once every 12 hours while in the sleep state.

The loggers were deployed with 4 x C cell Zn-MnO alkaline long life batteries, each with a capacity of 7800 mAh and manufactured by Varta. By having the functionality to detect a trip, the device can assume a low power sleep state and only wake and commence recording once the vehicle is in motion. Putting the device in a sleep state while not in use significantly reduced battery consumption, thus reducing the maintenance schedule requirements of the device. The device was configured to record and upload data every 5 minutes while the vehicle was in motion. When the vehicle was stationary, this period was reduced to record and upload every 12 hours. After 179 days of continuous operation, one of the loggers installed in a delivery van ran out of battery. In its lifetime, it recorded 29342 datapoints representing 1812 journeys: approximately 10 journeys per day.

To demonstrate the benefit of the trip detection algorithm on battery conservation, the battery performance of the logger with trip detection enabled was compared to that of a logger without trip detection enabled. Without trip detection enabled, the logger uploads data every 5 minutes regardless of if the vehicle is in motion or not. This results in 288 recordings made every 24 hours, every day, while there is enough battery capacity to power the device. Using the average voltage consumption per recording, an approximation of how long the logger would have lasted without trip detection enabled was made. Assuming that the logger uses the same power consumption whether trip detection is enabled or disabled, a battery life estimate can be provided.

At 288 recordings per day, the life expectancy of the logger without trip detection enabled is estimated at 19683 / 288 = 68.35 days.

This is a 61.8% decrease in performance from the trip enabled logger, which recorded data for 179 days in total before battery exhaustion. Figure 4 visualises the difference in battery degradation between the logger which has trip detection enabled (blue plot) versus the logger which has it disabled (purple plot). From this, the ~2.5 times performance increase the algorithm has on battery life can be observed.

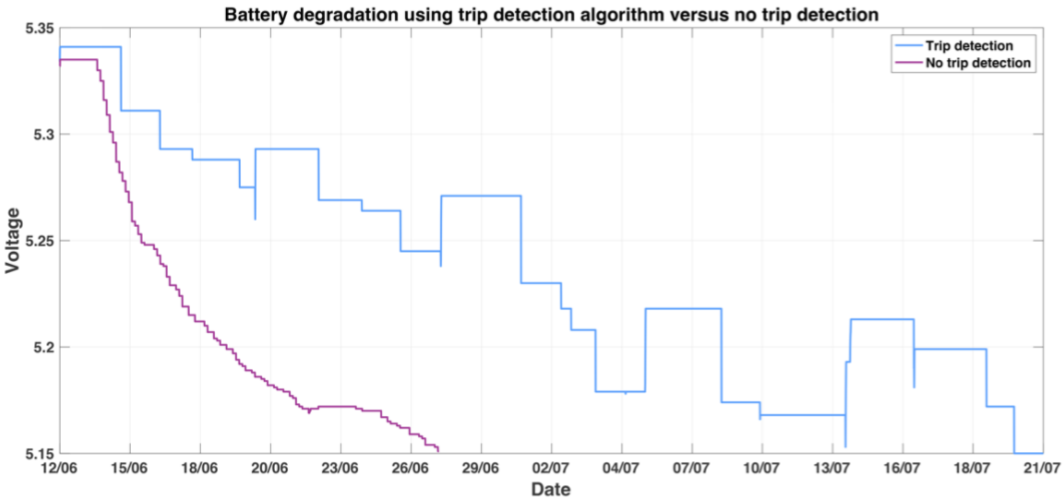



*Figure 22: Battery life performance of the logger using trip detection (blue plot) and with trip detection disabled (purple plot).*

## 4.7 Configuring alerting

For the alerting algorithm, trip detection status is used as the first condition to ensure the vehicle is in motion. Musgrave knew vans had a cool down period of approximately half an hour and so did not want to receive an alert until this time had elapsed. Since recordings are uploaded every 5 minutes, the trip condition should therefore be true 6 times before progressing to the next stage of the alerting. Next, temperature threshold abuse is checked. To ensure detection anomalies are avoided, the temperature threshold should be passed twice before sending an alert. Figure 6 shows the alerting criteria configured on the Whysor dashboard.

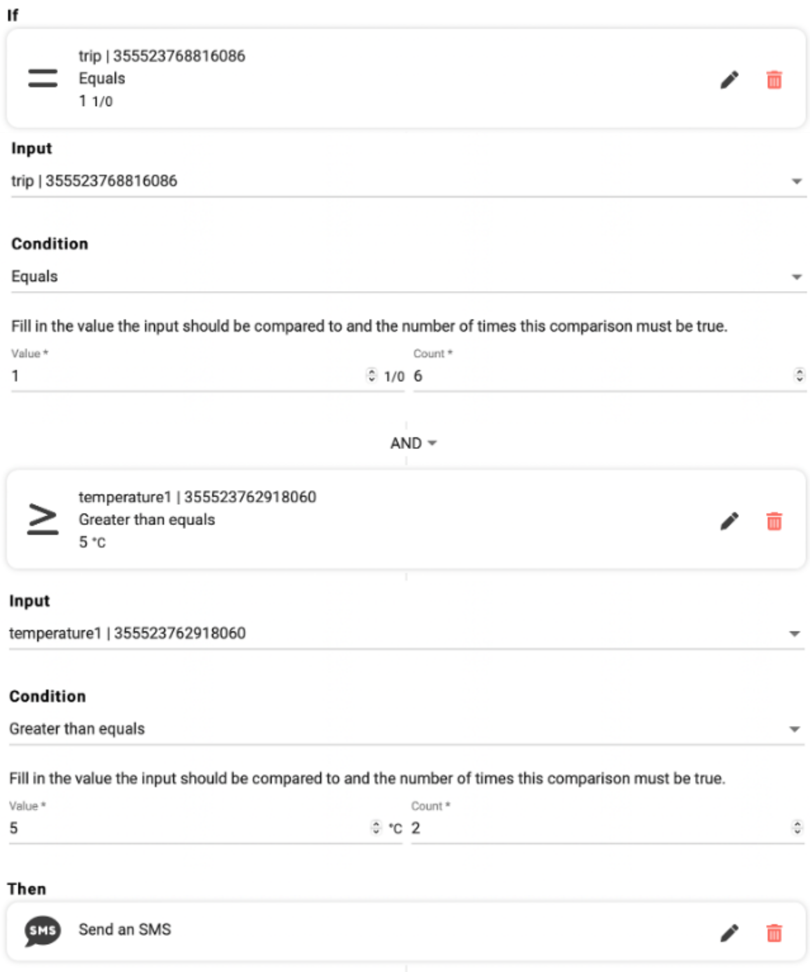


*Figure 23: alerting criteria configured on the Whysor dashboard*

## 4.8 Relationship with the company through the pilot test

There are three main contacts at Musgrave for the REAMIT project. The lead is Robert Gallagher, Supply Chain Manager, joined by Jon McKenzie, Warehouse Manager and Keith Neil, Logistics Manager. While Robert acts as the contact point for planning and approval of research activities, Keith is the main contact for "on the ground" activities i.e. sensor installation / practical aspects of the pilot study. Each of these contacts have been very responsive and receptive to both email communication and on-site visits. Musgrave are very willing to participate in research activities and have no issues using their name in research works / case studies etc.

## 4.9 Communication and dissemination activities

A newsletter piece and an academic poster have been prepared outlining the Musgrave pilot study. Rich Osbourne of Type40 Creative also attended Musgrave to record the installation of the sensors in the vans, and on a second visit performed interviews with Robert Gallagher and Trevor Cadden. Musgrave have their own 5-minute section in the documentary which is incorporated in the full video and also available as a standalone piece on Youtube. An oral presentation on results from the Musgrave trial was provided at the 36$^{th}$ European Federation on Food Science and Technology Conference in Dublin, Ireland, on 7-9 November 2022. A research article entitled "Real time anomaly detection for cold chain transportation using IoT technology" documenting the work carried out for the Musgrave pilot was published in the MDPI sustainability special issue.

**Table 1.** Communications generated by UU for Musgrave

| Communications | Date and Place | Number |
|---|---|---|
| Posters | **2022 :** REAMIT dissemination material (on display at 2022 Symposium) | 1 |
| Oral presentations | **2022:** European Federation on Food Science and Technology (EFFoST). Dublin | 1 |
| REAMIT symposium | **2021:** Dublin (UCD) **2022:** Nantes (UoN) | 2 |
| Videos | **2022:** REAMIT documentary; individual Musgrave video (youtube) | 2 |
| Article(s) | **2023:** Real time anomaly detection for cold chain transportation using IoT technology. MDPI Sustainability | 1 |

### 4.10 Other best practices and lessons learned

Careful consideration needs to be given to the chosen sensor location to monitor ambient temperature within vans. Ambient temperature monitoring can fluctuate as much as 10oC+ depending on the chosen installation location of the temperature probe. We believe, after experimentation, that the true reflection of ambient temperature within the van is located at the 'air on' site of the refrigerator, which is where the air is drawn back into the compressor after circulating the entire van.

Initially, we had the sensor probe stuck to the roof of the van and had found higher than expected temperature values recorded. Therefore, after an initial 6-month dataset was collected and further research on sensor location was conducted, the sensors were repositioned to the 'air on' of the refrigeration unit (Figure 7). Note that in the first iteration of the trial, the temperature / humidity probe was used in the freezer compartment and the temperature only probe was used in the chill compartment. This was changed for the second as humidity is linked to chilled food perishability while it does not affect frozen goods.


*Figure 24: Repositioned sensor locations. On left, the freezer zone sensor has been moved to monitor 'air on' at the compressor, and right, the chill zone temperature / humidity probe is attached to the roof.*

**External power**

While enabling trip detection has increased battery performance significantly (~6 months), sensor maintenance is still an issue when working with a large logistics company. Therefore, we recommend that, if possible, external power should be added to the loggers so that the maintenance window is reduced much further.

**Trip detection sensitivity**

The sensitivity of the trip detection algorithm is configurable by adjusting the time out between GPS readings. For Musgrave NI, the detection window was every 5 minutes, meaning this was the time between GPS location checks to detect if the van was in motion. However, if the system was deployed in a traffic dense city, the users of the system could increase this parameter accordingly. Extending the window between trip checking could help ensure trip status remains valid in the case of a traffic jam.

# 5 Northern Irish Pilot: WD Meats

## 5.1 REAMIT Pilot Test Storytelling: WD Meats (NI)

Located in Coleraine, Northern Ireland, WD Meats have been supplying quality assured beef and innovative beef products to retail customers throughout UK, Europe, Africa and Asia for over 35 years. WD Meats select only the best local beef that Northern Ireland has to offer. Then they process and deliver it with the utmost care and attention to the animals, and to the highest standards that their customers demand. Total traceability of the livestock, their husbandry and welfare all form part of product specification at WD Meats. WD Meats has a modern, 100,000 sq ft plant, built on a 35 acre site, which incorporates every aspect of the company's processing operation under one roof. The Slaughtering, Boning, Packing and Despatch facilities are all provided in-house, which gives them complete control over all stages of production. This means customers can be assured that the highest standards are maintained throughout. WD Meats employs over 400 staff and have annual sales in excess of £62 million.

## 5.2 Recruitment

Initially, Dunbia (NI), a red meat processor had been included on the REAMIT project as a full partner. However, after lack of engagement from the company, it was decided to dissolve the partnership and reallocate their funds to another company where REAMIT technologies could be piloted instead. Elaine Ramsey, Professor of Business Innovation at Ulster University had previously worked with WD Meats on other research projects and organised a meeting to present the REAMIT project to the company in February 2020. WD Meats were very interested in the project and agreed to join the project as a sub-partner of Ulster University.

## 5.3 Food waste issues at WD Meats

Marc Logan, New Product Development Manager at WD Meats identified two different areas of potential food waste which could be explored by the REAMIT team. Firstly, there was an opportunity for optimising the dry-ageing process. This is a 21-day cycle used for premium cuts of beef to both improve the tenderness of the beef and enhance the flavour, achieved by maintaining temperature and humidity in a sealed, refrigerated room. The ideal parameters for this room are still being explored, and so Marc proposed the REAMIT team fit sensors to the room to help map the conditions during the current ageing process versus the trim loss experienced, and through parameter tuning on future iterations help identify more "ideal" parameters to reduce the weight percentage lost during the process, while avoiding the dark-face phenomenon. "Dark facing" meat forms when too much moisture is drawn from the hindquarter, which must be cut off (or trimmed) prior to sale. This meat is classified as food waste.

Secondly, there is a recurring issue with Clostridium Estertheticum appearing on the production line, an anaerobic bacterium which causes meat spoilage. It is commonly found in the digestive tracts of animals, including cows, and can contaminate large quantities of meat during processing or handling as it is easily spread. This bacteria produces a strong and unpleasant odor, known as "sour meat," and causes discoloration of the meat. Vacuum-packed meat is particularly susceptible to the growth of Clostridium estertheticum, which can cause a phenomenon called blown pack syndrome where the meat's packaging expands. Due to its ease of transmission on the production line, Clostridium can cause a large quantity of meat to spoil if left undetected. The current detection method relies on an external laboratory processing qPCR swabs twice weekly which takes approximately 48 hours from site swabbing to result. Acid washes are performed on site twice weekly already to kill all bacteria, but if clostridium is detected in the lab, production is stopped, and another acid wash is immediately performed. Marc was interested in any solutions the REAMIT team could provide to reduce the detection window of the bacteria from 48 hours, allowing WD to deal with the clostridium bacteria more quickly and reduce its impacts on production and meat loss.

## 5.4 Dry-Ageing at WD Meats

### 5.4.1 Selection and configuring of sensors

REAMIT needed to define an IoT architecture for the proposed dry-ageing monitoring system. LoRa sensors are the de facto choice for IoT solutions due to their long transmission range, even in noisy environments, and low power consumption. These sensors can survive long intervals between sensor maintenance, with some sensors achieving >8 years use on one battery. In some countries (such as the Netherlands), LoRaWAN is implemented at a country wide level, much like 4G cellular signal, meaning that LoRa sensors can connect to the cloud with no additional infrastructure. However, in the UK (where WD Meats is located) this infrastructure does not exist.

Instead, a LoRa gateway would need purchased and configured to connect the LoRa sensors to the cloud. For this, we selected the MultiTech Conduit mLinux LoRaWAN gateway, a configurable, scalable cellular communications gateway for industrial IoT applications. The LoRa gateway is registered on TheThingsNetwork (TTN), a global collaborative Internet of Things ecosystem that creates networks, devices and solutions using LoRaWAN.


*Figure 25: MultiTech Conduit mLinux LoRaWAN gateway with URSALINK UC-11 temp / humidity sensor*

From reviewing the literature, it was noted that for monitoring humidity in enclosed spaces, selecting a sensor with an external / protected humidity probe was required for accurate recordings. Probes with a foam exterior allow for the most accurate monitoring of humidity in a closed, humid environment as they allow moisture to absorb without letting the sensor become saturated and provide inaccurate readings. To this end, the Ursalink UC-11 was selected for the dry-age monitoring process. 5 Urslalink sensors were purchased to map one dry-age chamber at WD Meats. The sensor is IP67 protected and has an external probe, highlighted in Figure 2, below.


*Figure 26: Ursalink UC-11 with foam-protected temperature/humidity probe*

The sensors and gateway needed registered with TheThingsNetwork (TTN) to allow communication between the sensors and the REAMIT data server. It contains a LoRaWAN network server, built on an open-source core, allowing a user to build and manage LoRaWAN networks on their own hardware or in the cloud. TheThingsNetwork service acts as a 'middleman' between WD Meats sensors and the REAMIT server, translating the packets sent by the devices into meaningful data that can then be displayed and stored on the REAMIT dashboard / server. This service is the de-facto way to connect LoRaWAN sensors to the cloud. Once data is recorded in TheThingsNetwork, it can be retrieved, transferred, and displayed to REAMIT applications using the API / webhook functionality.

### 5.4.2 Procurement of sensors

The sensor and gateway orders were placed with Concept13 in October 2019 and October 2020 respectively. The sensors and gateway were configured by December 2020, but at this stage there were still various lockdowns due to the global COVID-19 pandemic and we could not access the site to install the sensors. Sensors were installed at WD Meats in July 2021.


*Figure 27: Initial installation position and mounting method (Velcro) of Ursalink sensors inside the dry-age chamber at WD Meats.*

### 5.4.3 Implementation of sensors

Due to the amount of signal attenuation expected from placing the sensors inside a heavily insulated container with large quantities of meat, which would undoubtedly absorb much of the signal, we wanted to place the LoRa gateway as close to the dry-age chamber as possible. Because the dry-age chamber was a 40ft refrigerated trailer located in the parking lot of WD Meats however, the gateway would have to be mounted outside and be placed in waterproof housing. A waterproof box was mounted to the palisade fencing in the parking lot in close proximity to the trailer, and the gateway was placed inside. Holes were drilled in the bottom of the casing for cable entry and for the antenna to protrude. A cover was then placed on the box to ensure it remained waterproof. Figure 4 shows the gateway location setup.

*Figure 28: Gateway installation at WD Meats. Waterproof box mounted to palisade fencing, with gateway located inside. Holes drilled at the bottom of the casing for cable entry and for the antenna to protrude.*

The Ursalink UC-11 Temperature and Humidity Sensors were installed in 4 zones of one of WD Meats dry ageing chambers, allowing us to accurately map the temperature and humidity gradient profile of the chilled room. Originally, the sensors were affixed to the wall of the dry ageing chamber using double sided Velcro (figure 3), but due to the large amount of humidity produced during the 3-week ageing process, some of the sensors came off the wall and were found on the floor, damaged.

The sensors were repaired, and a new strategy was decided upon whereby cable ties would be used to hang the sensors from the hooks that the hindquarters were also hung from. This would have the added benefit of a more direct line of sight to the gateway, with less meat in the way for signal absorption and attenuation. Moving the sensors from the walls to the hooks reduced overall packet loss and thus resulted in a less noisy datastream.

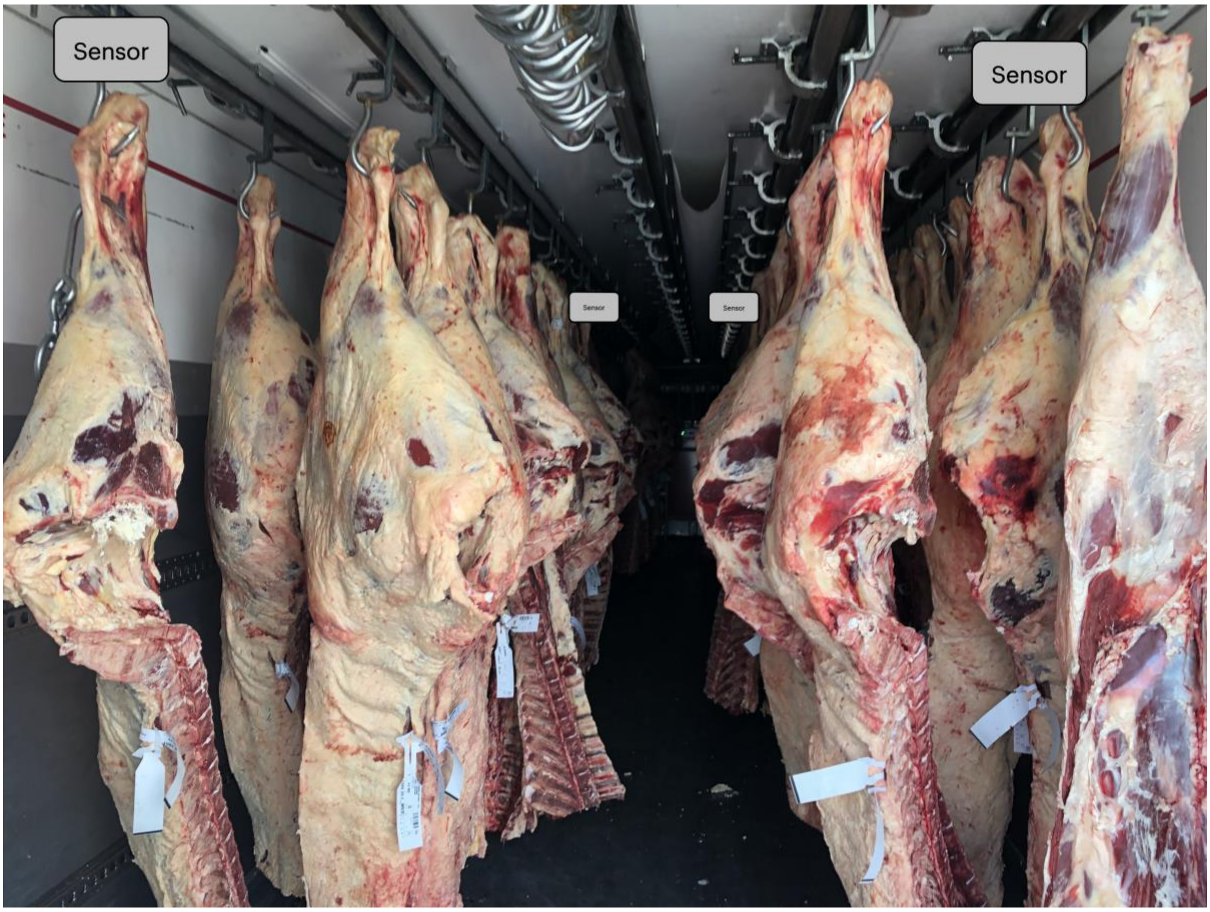



*Figure 29: Revised sensor locations and mounting method (hung from hooks using cable ties)*

### 5.4.4 Initial findings / analytics

The first question to examine was the relationship between temperature in the dry-age chamber and the weight-loss during the dry-age process. Before and after weights were collected on one load of hindquarters, and the temperature during the dry-ageing process extracted. Figure 6 shows the temperature mapping over the 14-day dry-age process, which illustrates how the temperature is clearly colder at the front of the dry-age chamber closer to the refrigeration unit compared to at the rear of the chamber, furthest away from the dry-age chamber. Closest to the refrigerator, the mean temperature was -0.7954, std 0.3274 over the 14-day dry age period. In comparison, furthest from the refrigerator, the mean temperature was 0.0164, std 0.3459 over the same period.

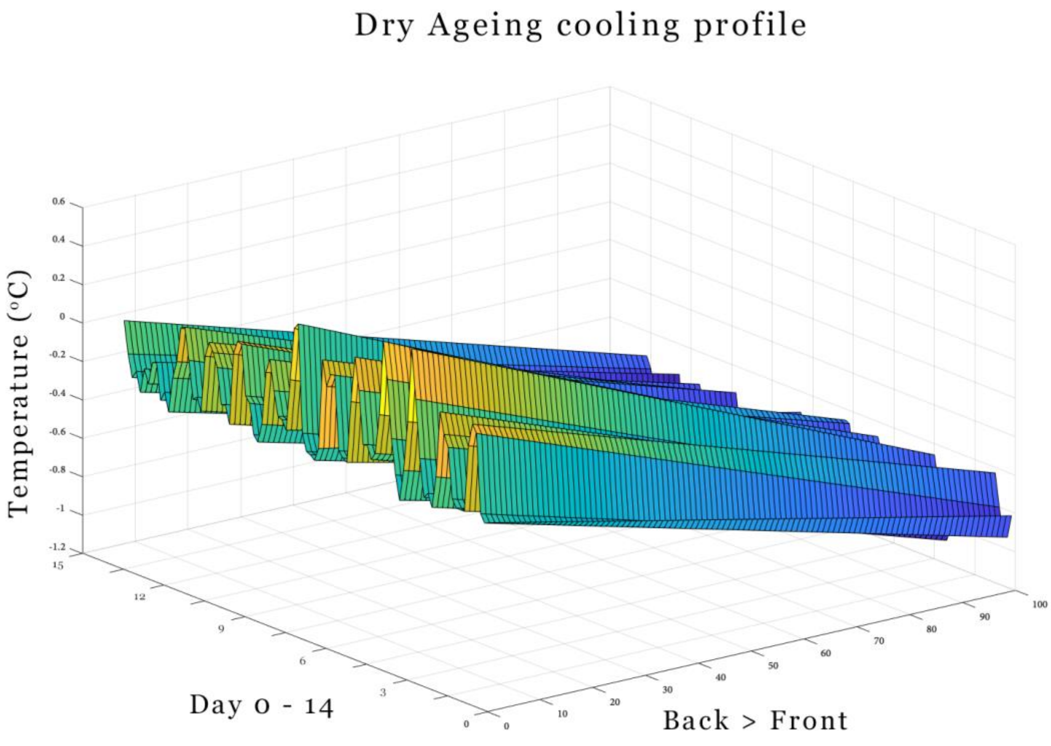



*Figure 30: Dry ageing profile over a 14- day period.*

The next step was to compare the weights of the hindquarters located in the front half of the chamber with those in the rear half. After the 14-day dry ageing was complete, the hindquarters in the front, cooler half of the chamber (closest to the fridge unit) had lost 3.87% total weight, while the hindquarters in the rear, warmer half had lost 4.33% total weight. An ANOVA (Analysis of Variance) test, a statistical test used to determine whether there are any significant differences between the means of two or more groups, was performed to check for statistical significance in weights between the hindquarter's storage areas. The result of the ANOVA test was $P<0.05$, telling us that the differences in weight loss between the front and rear were statistically significant.

From this initial analysis, we have learned that the cooler the temperature in the dry-age chamber, the less weight loss occurs on the hindquarters. The next step of the analysis is examining how much trim loss is observed caused by dark facings on the hindquarters located at the front of the chamber in comparison to those at the rear. With this baseline dataset, parameter testing on the refrigeration settings can be performed to see if an ideal set of parameters can be located which minimises both the water weight loss and the trim loss caused by dark facings.

## 5.5 Clostridium estertheticum at WD Meats

### 5.5.1 Selection and configuring of sensors, implementation, and results

The initial idea for the rapid detection of clostridium estertheticum was using a spectroscopy-based approach. FreshDetect GmbH, a German company, had developed a handheld 3D fluorescence spectrometer for fast and reliable quality control for the food industry. FreshDetect were named as part of the original REAMIT application and had loaned devices to Ulster for testing. However, after speaking to specialists in Spectroscopy at the University of Nantes, it was quickly discovered that the FreshDetect device would not have the required sensitivity to detect clostridium bacteria.

During the project, however, WD Meats were able to source their own qPCR machine. Announced in May 2019, the Genesig q32 provides test results within 60 minutes using genesig® kits, making it one of the fastest qPCR instruments on the market due to its rapid heating and cooling capabilities and unique lid design. It allows the analysis of up to 32 samples using fluorescence detection technologies, and at €13,500, is priced favourably for businesses to afford. By acquiring their own qPCR machine, WD meats would be able to perform their own on-site testing, reducing time from swabbing to results from 48 hours to approximately 1 hour. While qPCR testing is not be considered sensor technology and thus not within the scope of the REAMIT project, Ulster continued their collaboration with WD Meats for clostridium detection.

At the time of writing, lab scientists at Ulster have helped WD Meats validate their clostridium estertheticum controls. Ulster prepared positive strains of clostridium and ran the same samples on their lab-grade qPCR machine benchmarked against the Genesig machine at WD Meats. Ulster has given WD Meats the assurance that they can accurately detect the presence of clostridium on their own in-house equipment, hence they are able to perform on-the-spot site testing in the factory. As a result of this expert knowledge, support, and validation from Ulster's lab scientists, WD Meats is now able to conduct their own testing with confidence, reducing the wait time for results from 48 hours to just 1 hour.

## 5.6 Relationship with the company through the pilot test

The main contact at WD Meats for the REAMIT project is Marc Logan, New Product Development Manager. The project is also working with Victoria Connor, Quality Assurance Assistant. While WD Meats have typically “busy” periods, especially in the lead up to Christmas, Marc has been very responsive and receptive to both email communication and on-site visits and has kept the Ulster team well informed regarding the current state of operations at the factory. WD Meats have concerns about the use of their name in publications, especially if the content could negatively affect the company’s reputation. For example, they do not want their name mentioned in any studies involving Clostridium Estertheticum.

## 5.7 Communication and dissemination activities

A newsletter piece has been prepared outlining the WD Meats dry-ageing chamber pilot study. A case study on WD Meats has also been prepared as a journal article and is awaiting approval for publication. A poster is planned for the work on the dry-ageing chamber. If any publications come out of the Clostridium Estertheticum work, the name of the company shall be anonymised and simply referred to as an abattoir. There is a planned journal article comprising a comparative work between trim-loss at Burns Farm Meats where ‘active’ chill rooms are used, versus trim-loss at WD Meats where ‘sealed’ chill rooms are used for the dry age process.

## 5.8 Other best practices and lessons learned

During the first iteration of monitoring the dry-age process, the sensors were mounted to the side of the chamber using double-sided Velcro. However, due to the humidity build-up over the 21-day period of dry-ageing beef, the Velcro failed, and the sensors fell to the ground. Therefore, it is recommended that a more robust mounting solution is used to ensure sensors stay affixed in the correct position and so damage does not occur. We chose cable ties and hung the sensors from the hooks that the hindquarters go on for the next iterations.

Monitoring other dry-ageing chambers emphasised the importance of selecting a sensor with an external/protected humidity probe. Probes with a foam exterior allow for the most accurate monitoring of humidity in a closed, humid environment.

# 6 Northern Irish Pilot: Andy Keery Refrigeration

ANDY KEERY
TEMPERATURE CONTROLLED SOLUTIONS

## 6.1 REAMIT Pilot Test Storytelling: Andy Keery Refrigeration

Andy Keery, owner of rent-a-fridge, has over 25 years' experience in the refrigeration industry and has designed bespoke portable cold storage systems that he rents and delivers to anywhere in Northern Ireland & Ireland. Andy's portable cold stores appeal to a wide variety of clients, from fast food outlets based at festivals and supermarkets who are performing maintenance on their main fridges to florists, wineries, and more.

For Andy, it is vital that his portable cold stores are reliable. In the unlikely occurrence that a breakdown is detected, Andy offers 24-hour support and call-out ensuring that the customer's chilled products are not at risk of spoilage. Andy wanted a remote monitoring solution with visualisation to let him view current and historical data, and text alerting if any breakdowns were detected during a hire of one of his cold stores.

## 6.2 Recruitment

Andy Keery had previously performed van refrigeration maintenance for Musgrave Northern Ireland. He was a colleague and friend of Jon McKenzie, Warehouse Manager at Musgrave NI who, after hearing Andy mention an interest in remote cold chain monitoring for his business, informed him about the pilot currently ongoing at Musgrave with REAMIT. After an initial exchange of emails, Andy was very happy to participate in the research project and agreed to join as a pilot test company.

## 6.3 Food waste issues at Andy Keery Refrigeration

Andy recognised that there was potential for food waste to occur if an equipment failure happened in one of his cold stores while rented to one of his clients. As mentioned, Andy's cold stores are rented to a variety of clients, but they are mostly agri-food businesses. For the first iteration of the pilot, the cold store with REAMIT technology was deployed at the Belfast Christmas continental market, a festive outdoor market that is set up during the Christmas season in many European cities. These markets feature a range of stalls and vendors selling a variety of seasonal goods, including food, drink, gifts, and crafts. Andy's cold store had been rented by Dublin-based burger company Rockets, who were using the portable walk-in fridge to store the ingredients for their offerings (burger patties, cheeses, and condiments). These ingredients needed kept at a chilled temperature of 5ºC. If any equipment malfunction occurred at any point during the rental period, there was a risk of exceeding this temperature threshold. If this were to happen for a period exceeding 1.5 hours, any items stored in the fridge would need to be discarded to comply with legal storage regulations.

## 6.4 Selection and configuring of sensors

Andy's portable cold stores are rented to various clients throughout the year, typically on 1-4 week contracts depending on the needs of the business. This results in the location of the stores only ever being fixed for a couple of weeks at a time. REAMIT therefore needed to find a solution which would allow for location agnostic real time data upload. Since Andy Keery is based in the UK there was no country-wide LoRaWAN network present, and because his cold stores are always on the move, it was not appropriate to deploy LoRaWAN gateways at each new location.

The cellular logger system already trialled at Musgrave was deemed the most appropriate solution. This logger contains its own sim card and uploads data to the cloud using a 4G connection, much like a mobile phone. Digital Matter offer both a Falcon and Eagle device. For this pilot, the Eagle was selected which, while heavier, offers a longer battery life. The Eagle logger is customisable and contains I2C, RS232, SPI, and One-Wire communication buses allowing for a range of sensors to be configured to best suit the needs of the application.

Similar to Musgrave, Andy wanted to be able to monitor both the air on and air off of his refrigeration unit to allow for refrigeration efficiency calculations to be performed, so we had to configure the loggers with two separate temperature probes. The same setup as was deployed at Musgrave was replicated. We selected the 1.8m T9602 T/RH I2C probe by Amphenol (USA), and the 3m DS18B20 by Maxim Integrated (USA) which used the One-Wire communication bus.

*Figure 31: DS18B20 Temperature probe, T9602 Temperature and Humidity probe, Pololou 2119 voltage regulator*

Since the cold stores in this pilot are stationary, the trip detection system was disabled. This would allow recordings to be made and uploaded every 5 minutes, 24 hours a day, with no sleep schedule so that accurate monitoring could be performed while the stationary cold store was deployed with a client. However, disabling trip detection would result in significantly more power draw on the batteries. To compensate, an external power feed was added to the Eagle. External power (12v) was provided to the Eagle from the refrigeration unit which was powered by a generator. The figures below show where the external power was added to the Eagle (Figure 32), and an image captured during on-site installation at the Belfast Continental Market with Dublin-based burger company, Rockets (Figure 33).

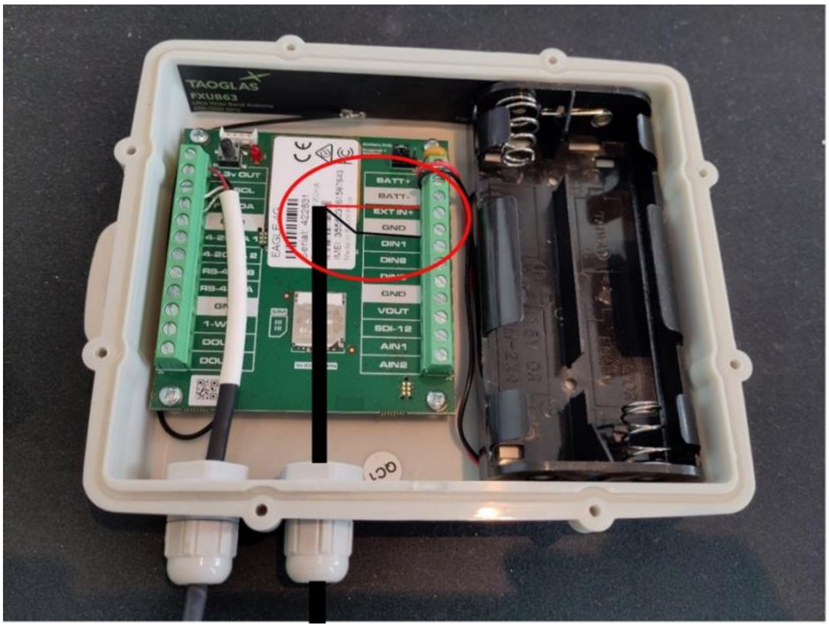



*Figure 32: Eagle logger with external power supply cable added.*

*Figure 33: Installation of the Eagle logger at Belfast's Continental Market.*

The Eagle was deployed with both external power and batteries installed in the logger. The logger was configured to prioritize external power as the power source when available. However, it automatically switches to battery power to continue real-time monitoring if the external power source is removed. In this way, data is captured and uploaded even if a breakdown in the refrigeration unit / power supply occurs.

## 6.5 Installation of sensors

The sensor order was placed as part of a larger order from Whysor with Digital Matter on 17th December 2021. The larger order was first shipped to Whysor (NL) and then the 5 loggers were repackaged and sent on to Ulster. These arrived at Ulster on 9 February 2022. 3 were used with Musgrave, leaving 2 loggers remaining for any other pilot work. The initial rollout of REAMIT technology with Andy Keery consisted of one of these loggers deployed in one rentable cold store. The sensor was installed on-site at Belfast City Hall on 19th November 2022 in preparation for the Belfast Continental Market launching at 6pm that day.

Figure 33 shows the sensor being prepared for installation. To allow the logger to be equipped with two temperature probes and an external power feed, a third cable gland was added to the logger. This ensured the external power connection could be added while retaining the IP67 rating of the device. The external power was taken from the refrigeration unit (pictured) and the logger was secured in place beside the gas for the compressor using cable ties. The sensor cables were run from the exterior refrigeration compressor to the inside of the cold store through a cable entry hole which already existed.

To reduce the invasiveness of the installation, cable ties were used as the mounting method of the temperature probes within the cold store (see Figure 34). The pilot test utilised 2 temperature sensors, one monitoring the ‘air-on’ of the fridge unit, which is where the air is drawn back into the compressor after circulating the entire store. This is where the true ambient temperature is monitored, and can be seen at the rear of the left hand photo in Figure 34. A probe was added to the 'air-off' of the fridge unit too. Air-off is where the air exists the compressor for the first time before it circulates the rest of the fridge and should produce a significantly colder reading. Andy was interested in monitoring the differences between the two monitoring locations as performance calculations could be performed with the data generated.

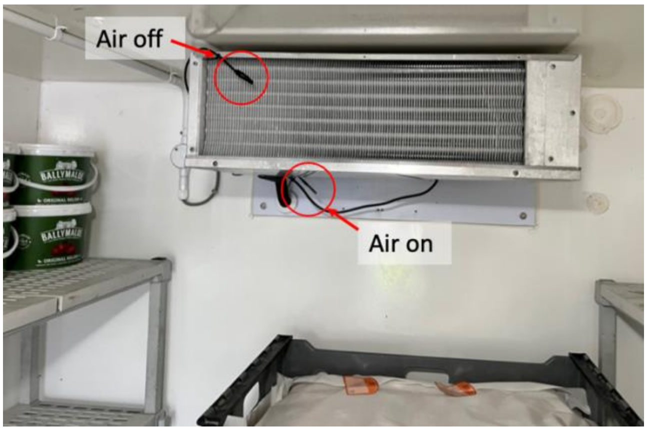


*Figure 34: Temperature sensors located in the cold store at the continental market. Front: Air off; Rear: Air on. Right: stock loaded in the cold store.*

## 6.6 Initial findings / analytics

The hire to Rockets burgers ended on 22 December when the market closed after 33 days in operation. Figure 35, below, shows a plot of the air-on ambient temperature during the entire monitoring period. The mean temperature over 33 days was 1.55°C, std 0.65.

As can be observed from the figure, the temperature during the monitoring period generally fluctuated between 0 and 2oC, ensuring products kept in the cold store maintained their freshness. Two interesting anomalies occur. Firstly, on 2 December at 10:26am, the temperature rises to 6.1°C. However, the temperature falls again to 3.25°C at 10:31 and by 10:36, the temperature has resumed to 0.43°C. The most likely explanation for this is that the fridge was being restocked during this time and someone had left the door open. Since temperature abuse needs recorded for 1.5h before the load is considered spoiled, no alerts were sent, and no food was wasted during this period of stock loading.

The second noteworthy observation took place between 00:45 and 7:45 am on 3rd December, over a period of 7 hours. During this time, the temperature gradually increased from 1.5°C to 4.06°C before returning to normal levels. After consulting with Andy, we believe that the generator ran out of fuel overnight, causing the fridge to stop working temporarily. Fortunately, due to the unit's excellent insulation, the temperature did not exceed the critical threshold, and no stock was wasted. This issue was detected promptly because the market had staff on-site every day. However, this scenario highlights the value of REAMIT's temperature monitoring IoT solution. Under different circumstances, the system could have alerted Andy and his client of equipment failure through a text message, enabling intervention before any spoilage of stock occurred.


*Figure 35: Temperature monitoring graph during deployment at Belfast Continental Market*

## 6.7 Relationship with the company through the pilot test

Andy Keery is the CEO and owner of Andy Keery Refrigeration. He has been very responsive and receptive to both phone, text, and email communication and on-site visits. Andy has kept the Ulster team well informed regarding the current state of operations with his cold stores and is happy for his name to be used for communication material. He was enthusiastic to meet with REAMIT partners Whysor in January 2023 and provide feedback on the dashboard system.

## 6.8 Communication and dissemination activities

A newsletter piece documenting the recruitment of Andy Keery, the launch of the first pilot at Belfast Continental Market, and a partner visit with Whysor in January 2023 appeared in the February 2023 newsletter.

## 6.9 Other best practices and lessons-learned

**Sensor location**

Careful consideration should be given to the chosen sensor location to monitor ambient temperature within cold stores. Ambient temperature monitoring can fluctuate as much as 10oC+ depending on the chosen installation location of the temperature probe. We believe, after experimentation, that the true reflection of ambient temperature within the cold store is located at the 'air on' site of the refrigerator, which is where the air is drawn back into the compressor after circulating the entire store.

**Future work**

In the future, Andy would like to see an option to toggle alerting on and off from the main dashboard screen. This functionality would be particularly relevant for Andy who will have his cold stores in his yard unused during weeks of the year; therefore, while not in rent he could quickly turn alerts off rather than having to enter the management menu.

Andy would also like to see the functionality of the Eagle expanded to allow him to use the outputs of the device to trigger a remote defrost cycle from the dashboard. Whysor are currently investigating how this could be implemented.

# 7 Irish Pilot: Burns Farm Meats

## 7.1 Presentation of the pilot test company

Burns Farm Meats Ltd. is a long-established, family-owned company in north Sligo, Ireland. Their main activities include farming, operation of an abattoir, processing of organic meats, and delivery of retail orders to the public. As part of these activities, being firmly committed to animal welfare and providing meat of the highest quality, Burns Farm Meats runs a dry-ageing process to deliver tender cut meat of their own locally raised, fed and cared for animals.

Dry ageing of beef is a process aimed at improving the quality and tenderness of meat and enhancing overall customer appreciation. It is achieved by storing (hanging) meat carcasses in refrigeration chambers under controlled conditions for a period that normally takes from 2 to 3 weeks. Burns Farm Meats has 2 refrigeration chambers in which this process takes place.

## 7.2 The company recruitment

The recruitment of this company started with talks between the REAMIT team and the Contact Point for the Interreg North-West Europe Programme in Ireland at the Southern Regional Assembly, Sarah Davoren, in late 2021. In the following weeks, Sarah contacted various County Council offices around the country sharing the promotional REAMIT content created by UCD, NTU and other REAMIT partners. Among these offices, the Sligo County Council shared and informed of the REAMIT project to associated companies in the area and, a few months later, in early 2022, Burns Farm Meats expressed a positive interest and asked for more information about the project.

Ultimately, this chain of contacts led Burns Farm Meats and UCD to be in direct contact with each other. As they later told the REAMIT team, the ownership of the company had been just handed over to the former owner's sons, Cathal Burns, and his brother, Diarmaid. They were both then trying to modernise and expand the company as it had been growing steadily in recent years. After initial exploratory phone calls and subsequent, technically focused online meetings, both parties agreed to work together on the monitoring of environmental parameters in their refrigeration chambers and reduce waste. Burns Farm Meats were especially interested in the monitoring of the dry-ageing process. In fact, this was not surprising as, despite increasing the flavour and tenderness of the meat, this process is regarded as costly for abattoirs because of shrinkage of the meat, trim loss, and risk of contamination.

The first on-site visit made by the REAMIT team to the company's premises was on the 23rd of March 2022, which served to get familiar with the dimensions of the chambers and the technical requirements of the Internet of Things (IoT) architecture that was to be deployed.


*Figure 36: three members of the REAMIT team visited Burns Farm Meats for the first time in late March, 2022.*

### 7.3 Issues and challenges faced in terms of food waste by the company

The company reported that they had a loss of meat at each of the runs of the dry-ageing process which they had to trim. In Burns Farm Meats, they used their refrigeration units for other uses (storing other types of meat) since they were a growing, but small company and they have a limited amount of space available. This loss could be related to the door being open for too long leading to higher than desired temperatures. Due to the configuration of dry-ageing chambers, the proximity of beef products to heat sources such as doors and distance from refrigerators can affect the moisture content of the beef. These changes in beef moisture content can affect both business value and the overall quality of the beef. Burns Farm sought a system which would perform the following:

- real-time monitoring of environmental parameters, i.e., temperature and humidity, in the dry-ageing chambers;
- the proposed system should be such that maintaining the equipment does not become an arduous task and does not interrupt their day-to-day operations;
- an alerting system should send emails and/or SMS messages to staff notifying if any anomalies occur;
- understand the influence of more even distribution of temperature in the refrigerator on the quality of beef.

### 7.4 The selection of relevant sensors

As previously mentioned, a visit to Burns Farm Meats was carried out in late March 2022. This visit allowed the team to assess the dimensions of the chambers and technical requirements for the IoT architecture. Given these, UCD discussed with REAMIT partners the number and type of sensors to deploy. The dimensions of the rooms were as follows:

- Large chill – L: 6.35 m; W: 2.8 m
- Small chill – L: 4.26 m; W: 1.98 m

Based on these dimensions, the team proposed to deploy:

- 6 sensors in the big room: a pair of sensors would be deployed at the front, close to the door, one on each side of the room; then, likewise, 2 more in the middle and 2 at the back. Each sensor would be roughly 1.6 meters away from the next sensor.
- 4 sensors in the small room, two in the front and two at the back.

For the pilot with Burns Farm Meats, we chose traditional sensor technology, i.e., temperature and humidity monitoring, as the company was especially interested in these two parameters for environmental monitoring of their refrigeration chambers.

At the time this pilot was launched, the Ursalink UC11-T1 sensor that had been previously deployed at a pilot test company in Northern Ireland for a similar use case (dry-ageing monitoring) had been discontinued and was not available from our suppliers. For this reason, other sensors were evaluated. After screening of possible sensor solutions, the ELT-2 Internal Antenna (Elsys, Sweden) was chosen given its simplicity in terms of installation and configuration, compact size, waterproof feature, internal integrated sensors including temperature and humidity, as well as the fact that Whysor (technological REAMIT partner) had already experience working with Elsys sensors.

*Figure 37: Elsys ELT-2 Internal Antenna sensor.*

Due to a limitation in the LoraWAN network coverage in Ireland, the architecture sought to install a gateway device that could upload the real-time sensor data to the cloud. The gateway chosen for this particular case was the Kona Micro IoT gateway (Tektelic, Canada). This piece of equipment consisted of a compact-sized LoraWAN-enabled device which could be used to effectively upload real-time data to the cloud. The Kona Micro IoT gateway was to be deployed in the office space at Burns Farm Meats within reach from the sensors and connected via an ethernet cable to their Wi-Fi router.

## 7.5 The installation of the sensors

The screening of equipment, purchase, and pre-configuration arrangements of the sensors and gateway were carried out during the summer months in 2022. The pre-configuration involved registering the sensors and gateway to the The Things Network (LoraWAN network server) and establishing connection between the Things Network and the Whysor database.

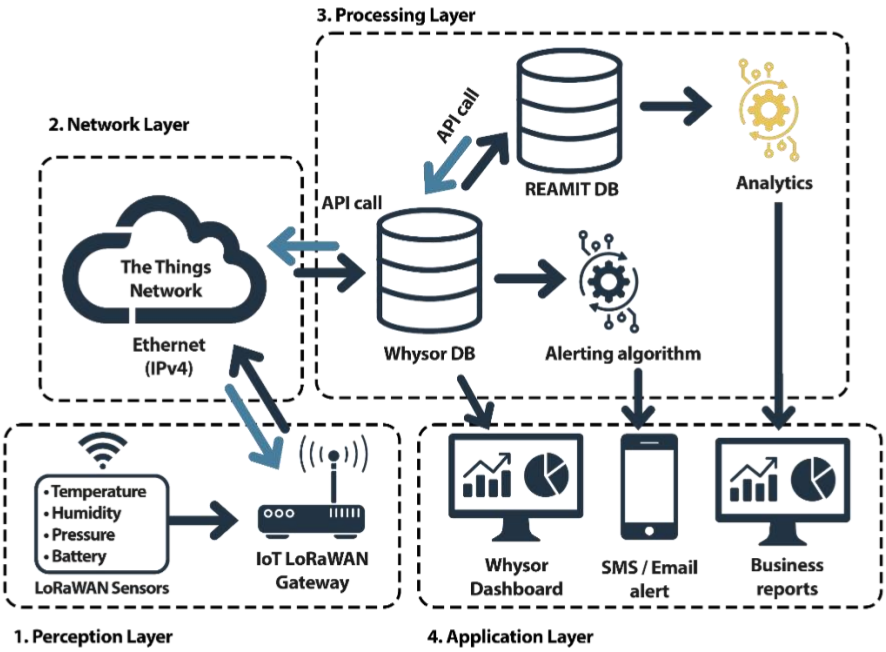



*Figure 38: This image shows the architecture that was deployed at Burns Farm Meats.*

The installation of the equipment at Burns Farm Meats finally took place on 7 September 2022 during an on-site visit made by the REAMIT team to their facilities. No technical issues occurred with regards to the equipment and from that date, data were being collected and uploaded to the server successfully. Sensor default setting of transmitting a recording every 10 minutes was left unchanged – if a configuration change is desired, Elsys has an app available on Google Play Store which allows for communicating to the sensors using a smartphone and via Near-Field Communication (NFC).

*Figure 39: Photograph taken during the sensor-installation visit on the 7th of September 2022 at Burns Farm Meats.*

In order to place the sensors in locations that did not result invasive or intrusive to their operations, while assuring that they would remain safely and locked into place, these were set at a height utilising the metal structure used to move carcasses in and out of the chambers, but in such a way that they did not obstruct or came into contact with the meat at any point.

*Figure 40: Photograph taken during the on-site visit showing the placement of one of the sensors.*

## 7.6 The implementation of the sensors

Soon after the installation of the sensors, Burns Farm Meat owners were given access to the Whysor dashboard from where they could monitor the environmental conditions of their chambers at any time.

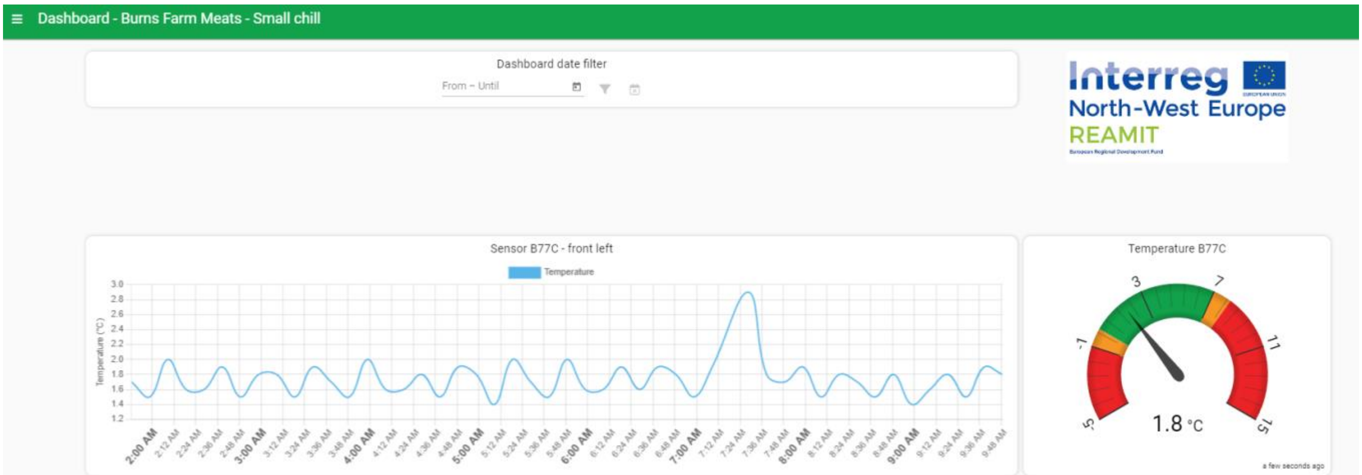



*Figure 41: Dashboard screenshot example showing the temperature results for one of the sensors.*

Two main challenges were encountered as for sensor implementation. The first one was related to SMS/email alerts warning about temperature and humidity anomalies in the chambers. Due to their activities and restrictions in terms of space in the refrigeration chambers, there were times that staff needed to open the doors for a certain amount of time to load/unload meat or for cleaning procedures. That lead to the conclusion that the implementation of an alerting system warning of environmental anomalies would notify staff repeatedly at times when they were aware of the door being open. To refine the alerting system and account for the door being open for a given time before sending alerts, the REAMIT team decided to add an external switch probe, a Surface Aluminium Contact Normally Closed (Challenger, UK), to one of the already installed ELT-2 sensors. This was carried out on the 22nd of February 2023 as the REAMIT team visited Burns Farm Meats premises. The switch, consisting of two separate magnets that when not in contact output an "open" (1 as opposed to 0) signal, was wired to one of the sensors (one of two closest to the door), while one of the magnets was placed at a heigh on the surface of the door and the remaining one was attached to the metal structure in a similar fashion as sensors were - and at the same height as the other magnet so that they would come in contact when doors were closed. To date (March 2023), a switch probe is still pending of getting installed in the smaller of the refrigeration chambers at Burns Farm Meats, however, this is expected to be carried out in the near future.

*Figure 42: Image showing the Surface Aluminium Contact Normally Closed switch.*

The second of the challenges was faced by the REAMIT data analytics team. This was related to the need for additional types of data to meaningfully link temperature and humidity recordings to amounts of food loss or statistic figures that could inform about the performance of their refrigeration units and distribution of heat within the chambers. To address this, the team had several meetings specially focused on Burns Farm Meats analytics over the months of December 2022 and January 2023 to discuss and evaluate options going forward to be able to provide the company with valuable insights that they could use alongside the dashboard for active monitoring of the chambers. To this end, the team concluded that asking about the possibility of recording weights was the best option in that regard. Since then, some data on weights were collected with the company's help during the on-site visit on 22 February 2023, and some more is expected to be collected before the end of the project in July 2023.

## 7.7 Relationship with the company through the pilot test

All throughout the time REAMIT and Burns Farm Meats have worked together, the relationship has been highly positive, and a collaborative framework has been established between the two parties. In fact, Burns Farm Meats has been involved in the development of REAMIT communication and videographic materials, has welcomed the REAMIT team on several occasions at their premises for technical assessment, sensor installation, filming, weight recording, among others. Moreover, they have conceded two interviews, one of which was filmed and featured in the REAMIT documentary, and another which was conducted as part of a qualitative survey on IoT implementation.

From the REAMIT side, efforts have been continuously made to provide them with a monitoring tool and supporting them in the study of their refrigeration chambers.

## 7.8 Communication and dissemination activities

A list of all communication and dissemination activities can be found below:

- Poster: One poster was developed for promoting the Burns Farm Meats pilot test and displayed during the 4th REAMIT symposium in Nantes, December 2022.
- Video: Burns Farm Meats featured in the REAMIT documentary video available under different formats on REAMIT's YouTube Channel.
- Newsletter: The visit carried out in September 2022 for sensor installation featured in the REAMIT newsletter (September 2022 edition) and also made available on REAMIT's website. The developed poster was also made available on REAMIT's website and mentioned in the December 2022 newsletter.

Ongoing work (not completed):

- Journal article: A journal article is under development (March 2023), pending collection of additional data and the company's approval.

## 7.9 Other best practices and lessons learned

The sensor solution that was chosen for this pilot test, although with features that were considered advantageous, consisted of internal probes (enclosed within the ELT-2 outer box) for measuring temperature and humidity which were utilised for the environmental monitoring. At present (March 2023), efforts are still being made to validate the recordings of humidity as these were higher than expected. It was suggested that perhaps internal probes were not the best suited for measuring humidity as the air flow might be restricted and moisture getting trapped inside. Future work is expected to be carried out to determine whether the humidity readings coming from the ELT-2 sensors are correct or other sensors/external probes would have been a better fit for humidity monitoring.

## 7.10 Future work

Below is a list of the actions that the REAMIT team has planned on finalising before the end of the project in July 2023:

- Validation of the humidity readings by installing an additional logger coupled with an external probe
- Recording of trim loss and water loss weights related to the dry-ageing process
- Data analytics for obtaining a higher understanding of temperature and humidity distribution within the chambers, and the relationship of these parameters with the trim loss and water loss recorded
- Journal article on the monitoring of quality parameters of the dry-ageing process (pending collection of additional data and the company's approval)

# 8 French Pilot

## 8.1 Nantes University – GEPEA

The University of Nantes is a public research university located in Nantes, France. Founded in 1460, it is one of the oldest universities in Europe. The university is known for its strong emphasis on its commitment to providing high-quality education to its students and interdisciplinary research.

GEPEA (Genie of Environmental Processes - Agribusiness) is a research organization that is part of UMR CNRS 6144. It focuses on studying the processes that occur in natural and industrial systems in order to develop sustainable technologies and practices for the agri-food and environmental industries.

The research conducted by GEPEA covers a wide range of topics, including biorefinery, wastewater treatment, food processing, bioenergy, and environmental impact assessment. The organization is also involved in collaborative research projects with industry partners, other academic institutions, and government agencies.

One of the main goals of GEPEA is to contribute to the transition towards a circular and bio-based economy. This involves developing and implementing sustainable technologies and practices that minimize waste and environmental impact while supporting economic growth and societal well-being.

GEPEA has a multidisciplinary team of researchers, including biologists, chemists, engineers, and environmental scientists, who work together to tackle complex environmental and industrial challenges. GEPEA is home to five scientific teams, each with their own area of expertise:

- The BAM team focuses on bioprocesses applied to microalgae.
- The MAPS2 team studies matrices and food, including their processes, properties, structures, and sensory characteristics.
- ***The TEAM team*** specializes in air metrology and water treatment.
- The OSE team is dedicated to optimization, systems, and energy.
- The GREEN team works on energy and residue recovery, as well as emission treatment.

***The TEAM team*** is based in Nantes IMT-Atlantique and has been selected as one of the REAMIT partners.

## 8.2 Role of Nantes University in the REAMIT project

REAMIT project aims at "improving Resource Efficiency of Agribusiness supply chains by minimising waste using big data and Internet of things sensors". Our aim is to introduce a rapid technique known as "Raman spectroscopy" to monitor the quality of food during transport.

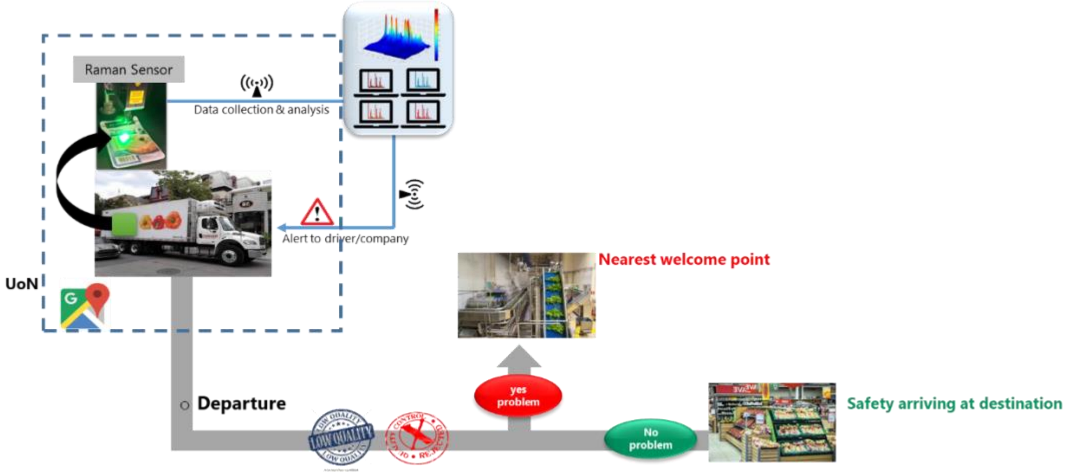



*Figure 43. UoN Roadmap for Implementing Raman Spectroscopy as a Quality Monitoring Tool*

## 8.3 Role of Raman Spectroscopy in Reducing Food Waste

Raman spectroscopy is a technique that is based upon the interaction of light with matter. The light emitted from the laser hits the sample, and the molecules within the sample start vibrating and emits a signal that is analyzed by the spectrometer. This signal or the "Raman spectrum" is considered as a structural fingerprint where it shows all chemical bonds that can be attributed to nucleic acids, carbohydrates, lipids, and proteins. The latter information is obtained within seconds and with no sample preparation and even without destroying or ruining the sample under testing and thus no food waste. The proposed system can help food industries (pilot tests) to monitor product quality and avoid food loss not only during transportation but also along the food production and distribution chain. For instance, monitoring raw material at the farm level in real time using the provided system is quite important as it can provide farmers with valuable information on raw material chemical composition.


This permit farmers to better optimize the farm management and cut foreseeable food losses. This is

*Figure 44. Raman Spectrometer potential in food waste reduction*

also doable at the factory level, where the ability of this portable system to detect changes at the molecular level in seconds can pick up any drastic quality changes in any food item (Vegetables, fruits and meats) and thus rushing its production. As for transportation, the portable version of Raman spectrometer can act as an alert system that can signal the driver to deliver the food products to the nearest food out-let or distribution centre in case of a possible food loss.

To accomplish the latter, especially the part on installation of the Raman system in a refrigerated truck, a pilot test needs to be recruited and a strategic plan is required for installing such system.

## 8.4 Pilot test - Recruitment

In 2019, approximately several firms have been reached out to with an invitation to join this project as industrial partners. The selected companies are involved in either food processing/production or refrigerated transportation. Out of the contacted companies, three showed interest and the list of contacted companies and their respective areas of focus are provided below:

- Routhiau, located in France, focuses on producing meat products, appetizers, desserts, cooked fruits, and vegetables.
- STeF, also located in France, specializes in cold logistics for temperature-sensitive and agro-food products.
- NUEVA PESCANOVA GROUP, based in France, is involved in the conception and packaging of seafood products.
- IGRECA is a French company, and is considered as a world leader in egg products
- Prince de Bretagne is a French agricultural cooperative that produces and distributes a wide range of fresh fruits and vegetables, with a focus on sustainable and responsible farming practices.

Out of the five companies, Routhiau has accepted in March 2020 to be a pilot tester in a collaboration aimed at extending the use of Raman spectroscopy for quality control beyond the industry and into the transportation sector.

## 8.5 Configuring and testing Raman sensor (from Lab testing to validation in real conditions)

The pilot program is designed to ensure the quality of food during storage and transportation by using a fast and effective technique called Raman spectroscopy, while maintaining refrigerated conditions. To achieve this, a comprehensive road-map was developed. The first stage involved testing the Raman sensor on food samples in the laboratory, analyzing the resulting data, and then uploading it to the server. This initial phase is known as "lab development." Next, the technology was tested under conditions similar to those found in refrigerated trucks, which is referred to as the "transitioning phase." Finally, the technology will be tested in real-world conditions, representing the third and final stage of the pilot program.

In summary, the pilot focused on three key stages:

1. Stage 1: Lab development
2. Stage 2: Transitioning phase
3. Stage 3: Testing in real conditions.

### 8.5.1 Stage 1 - Lab development

The first step taken towards achieving the project goals involved Raman measurements and statistical exploration. Multiple tests were conducted using Raman spectroscopy. The first test, which used Raman at UoN, was carried out on chicken meat samples between September and October 2020. The second test was conducted between November and December 2020, generating 150 Raman spectra daily for over a month. The pilot test Routhiau provided the samples. The resulting 4800 Raman spectra were then sent to Whysor and SenX for statistical analysis, with the goal of creating models for predicting sample quality. Prior to sending the data, UoN met with I&R, Whysor, and SenX to present various formats of Raman spectra and determine the most suitable format for the partners responsible for data analytics. The objective was to avoid using large files that could overload the server and slow down the transfer of Raman data. All partners agreed to use the TXT format. Additionally, time stamping was added to the names of the Raman spectra, which will be useful for creating statistical models in the future.

During this stage, an automated script was developed to extract data from the Raman system, save it on the local server, analyze it, and produce the final results.

After uploading the data, the Raman data analysis was carried out at GEPEA with the aim of demonstrating the feasibility of using the Raman sensor for monitoring chicken quality without packaging for a period of 30 days. The analysis of stage I data yielded a proof of concept, showing that the portable Raman system could effectively monitor the changes in protein structure as the storage time increased. These changes in protein structure are indicative of various spoilage reactions, such as microbial growth, protein denaturation, and amino acid residue oxidation. Based on these promising results, we decided to move on to stage II and tackle new challenges.


*Figure 45. Raman sensor testing with Routhiau samples – Proof of concept*

## 8.6 Stage 2 - Transitioning phase

The Second stage started in 2022. It should be noted that there was a year delay between stage I and stage II due to COVID. The second step initiated by the pilot was to make sure that the Raman spectrometer can operate normally under low temperatures to mimic the conditions encountered in the truck (transition phase: between Lab and company).

One of the main issues that we faced is that the Raman laser was not working at temperatures below 10 °C. To resolve such issue, we introduced a heating chamber for the laser and the optimal temperature was set at 18 °C.

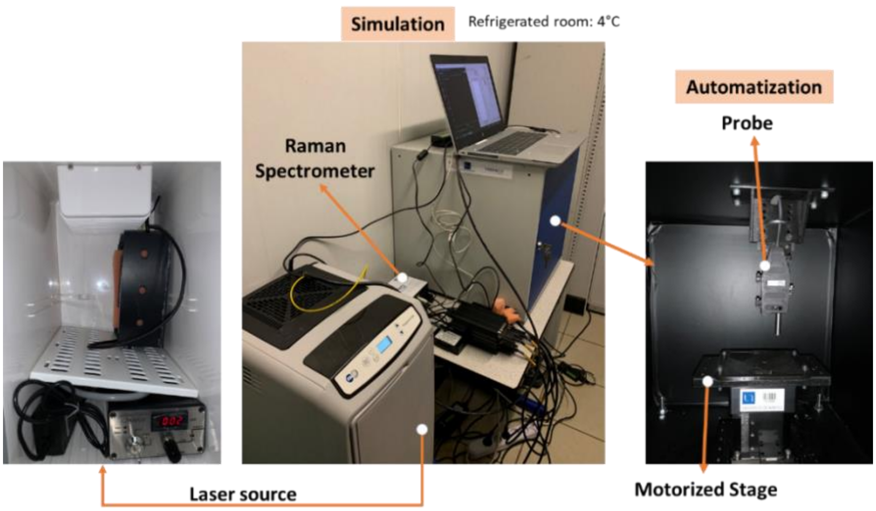



*Figure 47. Raman portable system in a refrigerated storage room*

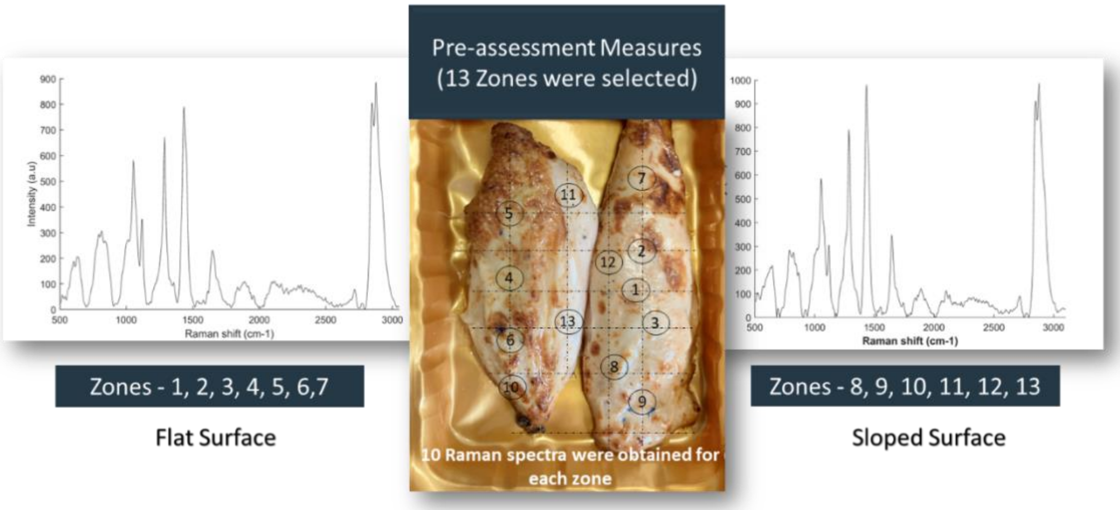
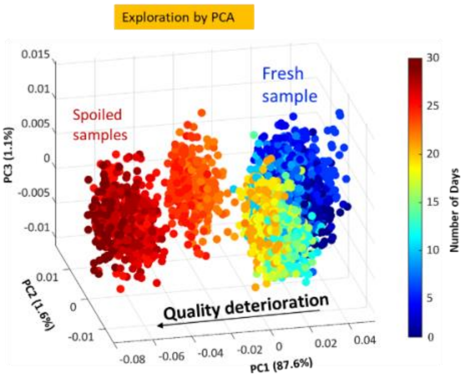



*Figure 46. Acquiring Raman spectra at different zones of the food sample*

After the system started working normally, several pre-assessment tests were conducted before initializing the quality monitoring process. The first test or challenge is surface topology. For instance, food samples like chicken had different surface topology.

With the help of the motorized stage, Raman spectra we were taken from 13 different zones as shown in Figure 47. The zones were then grouped into two main categories: Flat and sloped surfaces. Each group was analysed, and we came into a conclusion after several trials, that no matter where the Raman signal was acquired, the same signal was obtained.



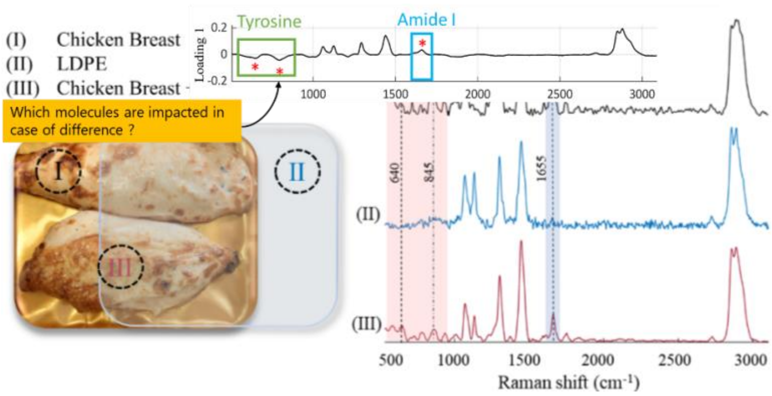




*Figure 48. Selection of the bands with no package interference*

The second stage of testing involved checking the quality of LDPE-wrapped chicken breast over 30 days. As known, LDPE has its unique spectrum and its Raman bands can be confused with those of chicken bands as shown in Figure 48. LDPE spectrum was therefore acquired and compared with the chicken spectrum (Figure 48). Only a few chicken-related bands were visible (Figure 48), which are Amide I (1655 $cm^{-1}$) and Tyr (845 and 640 $cm^{-1}$).

The next step is to validate the results and make sure that Raman spectroscopy is able to monitor the quality and overcome the challenges that had been stated earlier.

In the validation step, the quality monitoring process was started on 6 June,2022. Over the course of 30 days, the Raman acquired 30 spectra in the morning and another 30 in the evening, making a total of 60 spectra per day. The temperature was also being monitored over the course of the process.

After this process ended, the data were analysed. Here are some of the results obtained upon analysing the data acquired from the portable Raman system over 30 days.

Figure 49 shows that the portable Raman system was able to differentiate between fresh and spoiled samples and also was able to monitor the quality deterioration process as we go from day zero to day 30. Not only that, but the system was able to detect which molecules are impacted and in particular the amide I which is considered one of the major proteins in chicken and Tyrosine which is considered as an indicator of quality deterioration. Also, the system was

*Figure 49. Raman system capabilities on observing the quality change and detecting the molecules behind this change*

able to detect the day at which the first shift in quality happened. As shown in Figure 50, the first shift happened at day06, then again on day 12. At day21 a big drop in quality was noticed which indicates the start of the spoilage process started (Figure 50).

More details can be found on the system results in the article published in the Sustainability Journal: “Raman Spectroscopy Application in Food Waste: A Step towards a Portable Food Quality-Warning System”. In addition, our team focused on creating scripts that can automatically analyse the Raman data with minimum personal interference. All above results were obtained with an automatic script that can extract data and send it through a server for further analysis.

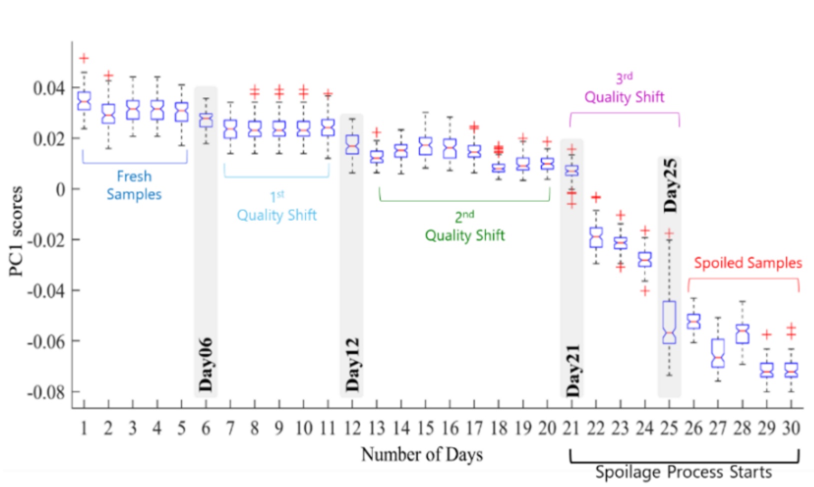



*Figure 50. Detecting the day on which the quality deterioration started*

These scripts can also pre-treat the Raman spectra (data), analyze and give the above results in matter of 2-5 minutes (depending on the size of data).

## 8.7 Stage 3 - Testing in real conditions

After validating the system capabilities, Routhiau was contacted to start the last step in our methodology. The final step of this project was to move the system to refrigerated food trucks and test it in real conditions. However, Routhiau was not able to participate in this stage. So, another plan was initiated which is “Renting a Truck” due to time limitations. A truck was rented on January 2023 for a four-day period (phase one). The truck had a refrigerated part of 13 $m^3$ pre-equipped with a temperature sensor to ensure optimal conditions for the testing conditions. During this phase, the UoN team focused on ensuring that the Raman sensor is securely fixed and protected from any vibrations that may occur during transportation.

Also, several tests on the sensor were executed to check its performance. After making sure

*Figure 51. Truck rental, first phase.*

the system is running well, the truck was rented again in mid-February (phase two) to continue

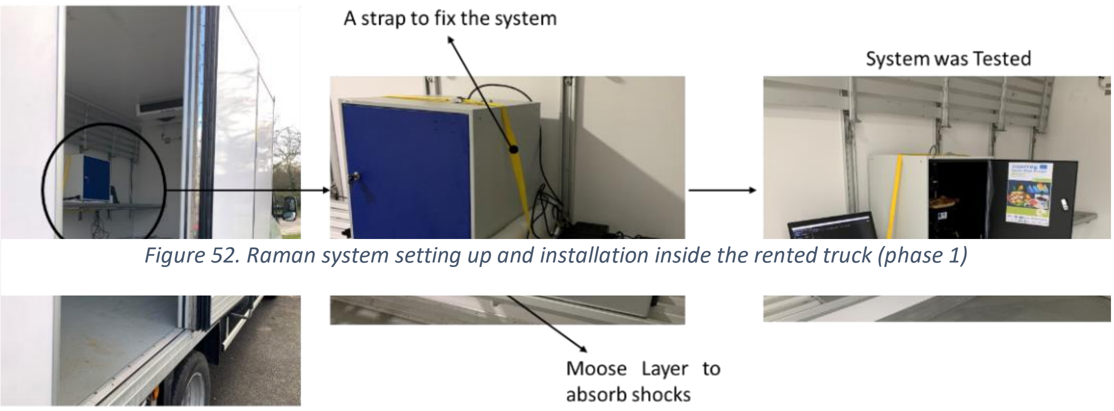



*Figure 52. Raman system setting up and installation inside the rented truck (phase 1)*

and finalize stage 3 “testing in real conditions”.

Before reaching the real time testing, one modification has been made to the portable system. As shown in Figure 53, small boxes were created using a 3D printer and were attached to the system. These boxes held all the Raman parts, thus taking less space when installed in the truck.

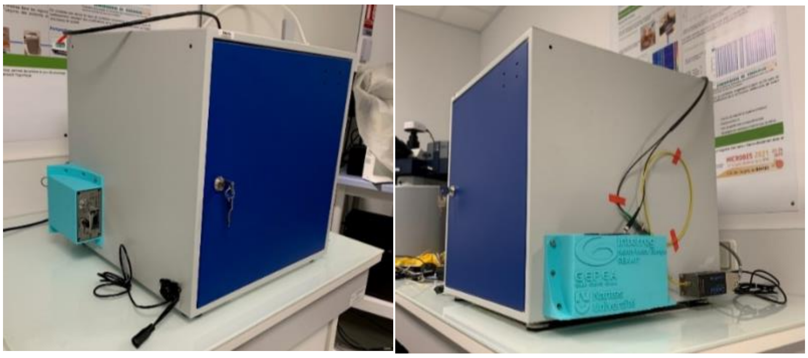


*Figure 53. Miniaturizing of the portable Raman system*

During the on-road testing conducted on February 2023, two challenges were observed:


*Figure 54. Raman test in real conditions, phase II*

- Road bumps affected the Raman signal.
- Sample holder’s shape needed to be adjusted according to the tested products

## 8.8 Relationship with the company through the pilot test

Routhiau was initially contacted via email to discuss the incorporation of Raman into their truck. Throughout the testing process, there was a constructive exchange of several emails and meetings (visit conducted to Routhiau), where Routhiau demonstrated a keen interest in the first two stages of the testing. They sent food samples for testing by the Raman system, which proved to be a valuable contribution to the project. While Routhiau did not express a desire to participate in the last stage of the testing, which involved incorporating the Raman system into their truck, they expressed their interest in using the technology during the receiving of raw materials and processing. Similarly, another company, Vives Eaux, also showed interest in utilizing the Raman system for these purposes. Overall, the testing and communication with Routhiau and Vives Eaux have been positive experiences, and we appreciate their willingness to engage with us in exploring the potential applications of Raman technology. The system has shown promising results in transportation, and we are excited about the possibilities for its use in other areas of the food industry.

### 8.9 Communication and dissemination activities

Although no dissemination activities have been carried out specifically with companies like Routhiau, the REAMIT partners have undertaken various dissemination activities. For example, Rich Osbourne from Type40 Creative visited the UoN-GEPEA laboratory and recorded the use of the Raman sensor, as well as conducting interviews with all the GEPEA staff involved in the REAMIT project. In addition, multiple posters and oral presentations were given at several national and international conferences, and an article was published in the Journal of Sustainability, MDPI. Furthermore, the results of the Raman portable system were shared at different REAMIT symposiums, where Vives Eaux, one of the industries present, showed interest in the system.

**Table 2. Communications generated by UoN**

| **Communications** | **Date and Place** | **Number** |
|---|---|---|
| Posters | **2019:** IMTA meeting in Brest, France; **2019:** NWE Impact Event in Tourcoing (France);<br>**2021 :** Microbes 2021, Nantes France ; **2023** : Ifremer conference, Brest, France | 4 |
| Oral presentations | **2022:** Spain (ISBC & XIX ISLS symposium) | 1 |
| REAMIT symposium | **2020: Nottingham; 2021:** held online**; 2022:** Nantes | 3 |
| Banners | **2020**: 2 Banners installed at GEPEA; **2023:** Banner fixed on the truck | 3 |
| Videos | **2020**: REAMIT Partners (YouTube); **2022**: Raman Sensor; **2023:** Field Test | 3 |
| Article(s) | **2022:** One article published (Journal of sustainability, MDPI) | 1 |

### 8.10 Other best practices and lessons

Based on results of our testing, Raman spectroscopy is a useful tool for observing changes in the quality and chemical composition of the chicken products. However, it should be noted that these changes require a certain amount of time to occur, typically at least four days in the case of chicken products. Therefore, it is not necessary to run Raman spectroscopy continuously during transportation. Instead, it is recommended to analyze the food product using Raman spectroscopy two to three times per day while the truck is stationary to avoid any vibrations from road bumps, which can impact the accuracy of the results. By doing so, a good quality spectrum can be obtained, allowing for accurate assessment of the product quality and chemical composition while reducing electrical consumption.

However, for the system to recognize to run in stationary phase, two components are needed. The first component is a raspberry Pi kit, which will help initiate the scan remotely without the need for physical proximity. Also, the kit possesses an LTE-M GMS shield, ensuring the transmission of the Raman data to the server to be analysed can be achieved regardless of the location of the spectrometer. This has, in turn, turned the Raman setup into a location agnostic analysis tool as it does not rely on any other infrastructure to operate. This component was added to the system recently with the help of our REAMIT partners from Ulster University.

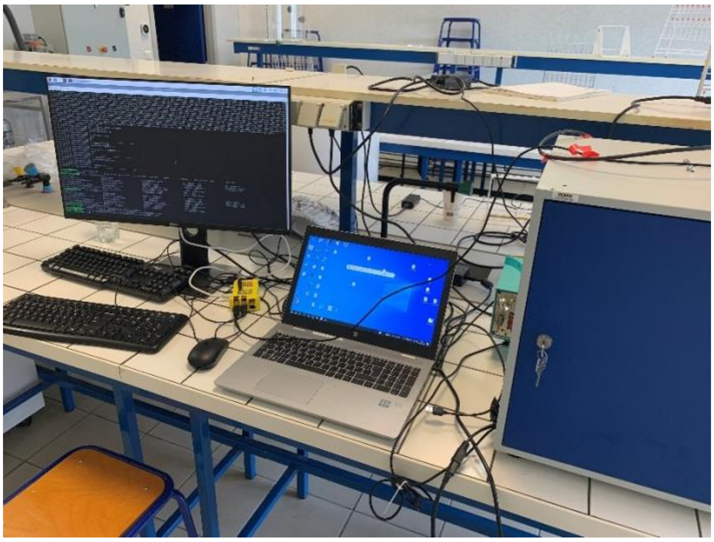


**Figure 55**. Installing the raspberry bi kit to portable Raman system

The second component is an accelerometer. This device can detect any type of movement or change in velocity. By integrating the accelerometer into the portable Raman system, it ensures that the scanning process is done in the stationary phase, thereby enhancing the accuracy and reliability of the results. The installation of this device is part of our ongoing plans for future improvements. It is currently being considered for implementation as we continue to develop and enhance our system.

# 9 UK Pilot: Glen Affric

## 9.1 Presentation of the pilot test company

Glen Affric, UK is a Brewery located in Liverpool. Write a bit about the company background

## 9.2 The company recruitment

Glen Affric (GA) was considered as a REAMIT pilot test company from Nottingham Trent University, UK. Agreement was signed between GA and Nottingham Trent University in March 2021

In Feb 2021, Mr Dan Bradley from Virtual Engineering Centre (VEC), University of Liverpool, UK contacted NBS - Prof Usha Ramanathan to discuss possible collaboration with REAMIT project. In subsequent meetings it was agreed to connect REAMIT with local businesses. After 2 rounds of meetings, Thomas and Morris from Liverpool University were introduced to discuss various possibilities of having REAMIT sensors in a brewery located in Liverpool. In the first meeting with Glen Affric Brewery, a team from the company has met with the project team, Usha Ramanathan and Ram Ramanathan along with Dan and colleagues from VEC.

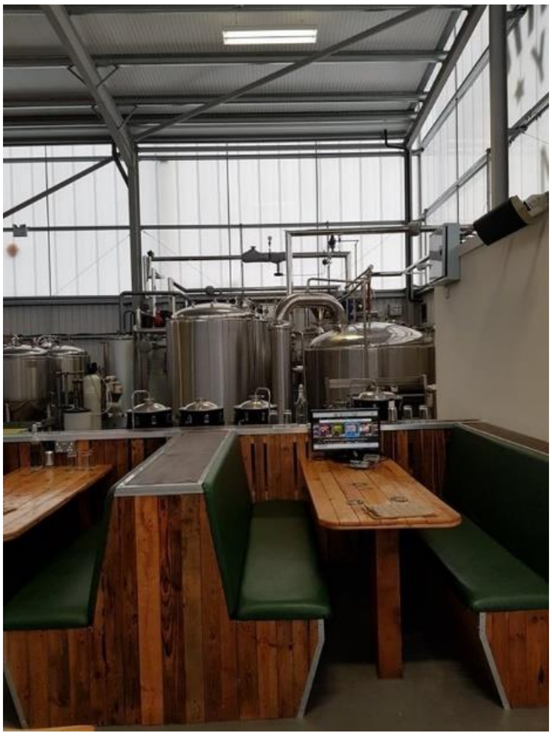
Then in the following meetings, Whysor (Marco and Imke) was involved in the meeting to discuss the possibilities of having sensors in various locations and the need of each sensor as per GA's requirements.

## 9.3 Issues and challenges faced in terms of food waste by the company

Glen Affric has been involved in production of alcohol related drinks (mainly Beer) from Barley. Storing the Barley grains within the premises was a bit of challenge during change in the climatic weather conditions. At the end of the production cycle the end-product is bottled and stored in the premises to be ready for the delivery. This warehouse temperature is also not fully temperature controlled and it is one the areas to be considered with REAMIT technology.

However, GA's interest of having sensors was mainly for the production process and hence asked the REAMIT team to fix sensors in the big storage tanks. Also, the flow meter was one of the requests made by the company to ensure the amount of liquid extracted from the mixing process. This will help monitoring the waste in the process.


MULTITECH



## 9.4 The selection of relevant sensors

Whysor installed a temperature sensor and a logger in the brewing site in Sep 2021.

The dashboard connection was provided to the company and also to the REAMIT analytics team. Any fluctuation in the temperature was giving alert in the system. It was working well until the pilot-test was terminated.

During Sep 2021- Jan 2022, six further meetings were conducted to see the progress of fixing other sensors namely humidity sensor and the flow meter. As flow meter was not really one of the expertise of the REAMIT partners, another company, Jumo, was invited to take part in the meeting to explore the feasibility of adding the flow meter.

After having some technical details in place, the REAMIT team started working on specifics of the measurement of the production facility of GA. The final meeting was held on 5th and 6th Jan 2022, to finalise the specifics of these technical details. Unfortunately Dan who was instrumental in bringing REAMIT with GA moved to a different work place and could not participate any more in this pilot-test project. Joosten from Jumo, sensor providing company along with Whysor, presented in the meeting. Trevor and Calum Mccormick (GA directors) represented GA management side and Lucio represented GA's operations side, Thomas and Morris represented Liverpool University, UK. This meeting was running for more than 80 minutes as it included several technical details. After this meeting, the company did not show any interest in going forward with the plan due to change in GA's management team.

Several reminders were sent to GA through emails from NTU and Whysor to make progress in the pilot-test. After 24 months of inception of this network, in Jan 2023, finally this pilot-test was called off and Nottingham Trent University team of REAMIT retrieved the equipment - sensor and lagger from the GA brewery which was sent back to Whysor by post.

### 9.5 The installation of the sensors

Temperature sensor and logger were installed in GA premised in Sep 2021.

### 9.6 The implementation of the pilot test

Dashboard data was live for more than 10 months of the installation of the temperature sensor. But no analysis was made as the temperature data will need to be matched with the actual condition in the brewery to compare the analysis and the underlying cause/impact.

### 9.7 Relationship with the company through the pilot test

Not willing to cooperate after change in the company's management reshuffling.

### 9.8 Communication and dissemination activities

After 23 months of initial connection with GA, the pilot-test was dropped in stage 2. No communication was made other than a brief mention in REAMIT newsletter in Sep/Oct 2021.

### 9.9 Other best practices and lessons learned

It is important to agree on type of sensors in line with the company's requirement possibly in a short duration to avoid future disappointments. One contact cannot be the backbone of the pilot-test success such as Dan Bradley and Lucio in this case As Dan left his job, GA was not interested any more. Also, Lucio was not connected to GA anymore.

# 10 UK pilot test: Human Milk Foundation

## 10.1 Presentation of the pilot test company

In 2016, Dr Natalie Shenker and Gillian Weaver set up the UK's first non-profit human milk bank, the Hearts Milk Bank (HMB). While the HMB got to work and sent donor human milk to hospitals, a team of parents, scientists, milk bank experts and doctors came together to develop the Human Milk Foundation (HMF) operating in Hertfordshire, UK. The HMF was launched on 1st August 2018 with the aim to build a new model to provide equitable access to donor human milk and breastfeeding support and initiate vital research and education on donor human milk.

HMF facilitates donor human milk supply to hospitals for the most vulnerable babies in situations where breastfeeding is impossible or taking time to establish. Currently, the annual capacity of HMB is approximately 5000 litters of donated human milk, transported by volunteering motorcycles (like 'blood bikes' delivering blood donated to UK hospitals). This volunteer-based system is almost unique to the UK. Although regulated as food, transportation of human milk falls outside the framework for food transportation in the UK. HMF is located in Daniel Hall Building, Rothamsted Institute, Harpenden, Herts, AL5 2JQ, UK.

## 10.2 The company recruitment

HMF was recruited as a REAMIT pilot test partner company in May 2021 through the social network channels i.e. friends talking to friends about how the REAMIT approach can help companies in food supply chains reduce food waste during food transportation. In May 2021, the director of HMF asked for the online meeting with the REAMIT team, and soon afterwards the REAMII team installed sensors in HMF milk bags transporting donor human milk.

## 10.3 Issues and challenges faced in terms of food waste by the company

While HMF has sophisticated systems to maintain the quality of donor human milk during storage in their premises, they found it challenging to ensure that donor human milk en route human milk donor – human milk bank – hospital/home of a vulnerable baby, is transported in the right temperature for maintaining the quality. Trips can be lengthy up to 8h since donors can be located as far as 1500 miles away, and there can be many journeys per day. Although milk is transported in insulated containers inside human milk bags, exposing donor human milk to temperatures above –15 degrees Celsius deteriorates its quality and suitability for consumption by vulnerable babies.

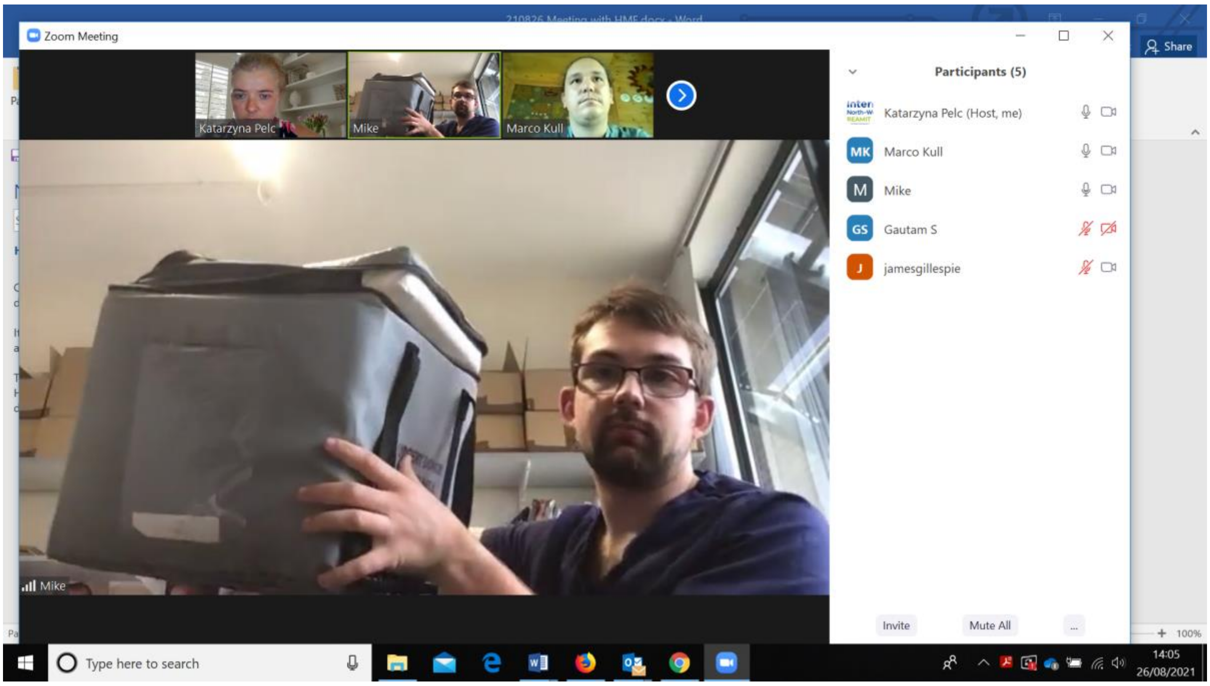



*Figure: Zoom meeting in summer 2021 attended by REAMIT partners from the University of Bedfordshire and Whysor, as well as from Human Milk Foundation to discuss the most suitable sensor to be fitted inside insulated bags used by HMF for transportation of donor human milk en route human milk donor – human milk bank – hospital/home of a vulnerable baby.*

HMF needs a system, which offers assurance that donor human milk is maintained in ideal temperature (below –15 degrees Celsius) during transportation.

The REAMIT approach based on the modern internet of things sensors, cloud technology and big data analytics can help in monitoring the temperature to ensure quality of donor human milk, and provide alerts if milk is not transported at optimal temperature. By monitoring temperature continuously during transportation, significant donor human milk can be saved.

REAMIT's ability to ensure the optimal temperature during transportation motivated HMF to engage with the REAMIT technology demonstration (aka pilot tests).

## 10.4 The selection of relevant sensors

Having assessed the challenge at HMF, REAMIT technology and data analytics partners proposed IoT temperature and humidity sensors for this pilot test. 2 temperature and humidity sensors were installed at HMF in September 2021 by partners from Whysor. Later, REAMIT technology and data analytics partners proposed adding binary sensors, GPS locator and accelerometer. BED has purchased the instructed equipment (10 new temperature and humidity sensors, and 10 binary sensors with GPS locator and accelerometer), which was installed at HMF in May 2022 by partners from Ulster and BED.

Sensors are battery driven and can send data every 2 or 5 min when a vehicle is driving. When a vehicle is standing, data can be sent at lower frequency. Cellular kind of connectivity NBIOT (band system in the UK for low power devises) was used in this pilot test due to distances to be covered during human milk transportation across the UK.

A binary sensor indicates if a milk bag is open or closed. The milk bag status (open/closed) is an indicator of temperature in which human milk is transported (temperature raising or not). A binary sensor is made of a magnet, and it can be in a human milk bag, wired and connected to a logger. The binary sensor can provide information if the human milk bag is opened intentionally during a trip, which can help increase security of the human milk inside the human milk bag, especially when the human milk is transported for more than one destination, and the bag is sealed. Partners from Ulster and Whysor worked jointly on the binary sensor implementation. Human milk bag is not translucent, but it is very dark. So, alternatively an optic sensor can be used for the bag status monitoring (open/closed), instead of a binary sensor.

Accelerometer within a logger detects motion. If there is no motion of a human milk bag, the sensor can go to 'sleep mode' to save the battery. Otherwise, data from sensors are uploaded to Whysor cloud every 2 or 5 minutes (depending on the set up), which is energy consuming. Accelerometer data help recognise steps of a trip. GPS data generated by sensors indicates if and when a sensor is in motion.

The REAMIT technology and data analytics team discussed a possibility for using a lightning sensor, which would pick up moments when a milk bag is opened and closed. This could be an idea worth exploring in the future, outside the scope of the REAMIT project.

Two temperature and humidity sensors installed in HMF in 2021 stopped working. The REAMIT team considered upgrading them by installing 2 additional functionalities: trip detection and bag status (open or closed).

## 10.5 The installation of the sensors

In 2021, at the start of this pilot test, technology and data analytics partners assessed that the required sensors for this pilot test are humidity and temperature sensors. On 27 September 2021, Whysor partners visited HMF and installed two temperature and humidity sensors inside milk bags transporting human milk en route human milk donor – human milk bank – hospital/home of a vulnerable baby and connected both sensors to the Whysor cloud. Both sensors were assembled by Whysor partners themselves. Sensors started to collect data from trips with donor human milk, and data were sent and recorded in the Whysor cloud.

Following the request from HMF, the REAMIT team scaled up the number of installed sensors and 10 additional temperature and humidity sensors and 10 binary sensors were purchased by BED early in 2022. Two new functionalities in the logger were enabled: GPS locator and accelerometer.

During a visit at HMF on 23 May 2022, the REAMIT team installed in human milk bags additional 10 temperature and humidity sensors and 10 binary sensors. New sensors were connected to Whysor cloud and started to record data from trips of human milk bags. All loggers have a GPS locator and accelerometer functions. With time, the REAMIT team learnt that sensors needed to be re-positioned inside the milk bag to better record data. Sensors were sent on multiple trips inside human milk bags and collected data on temperature conditions inside milk bags.

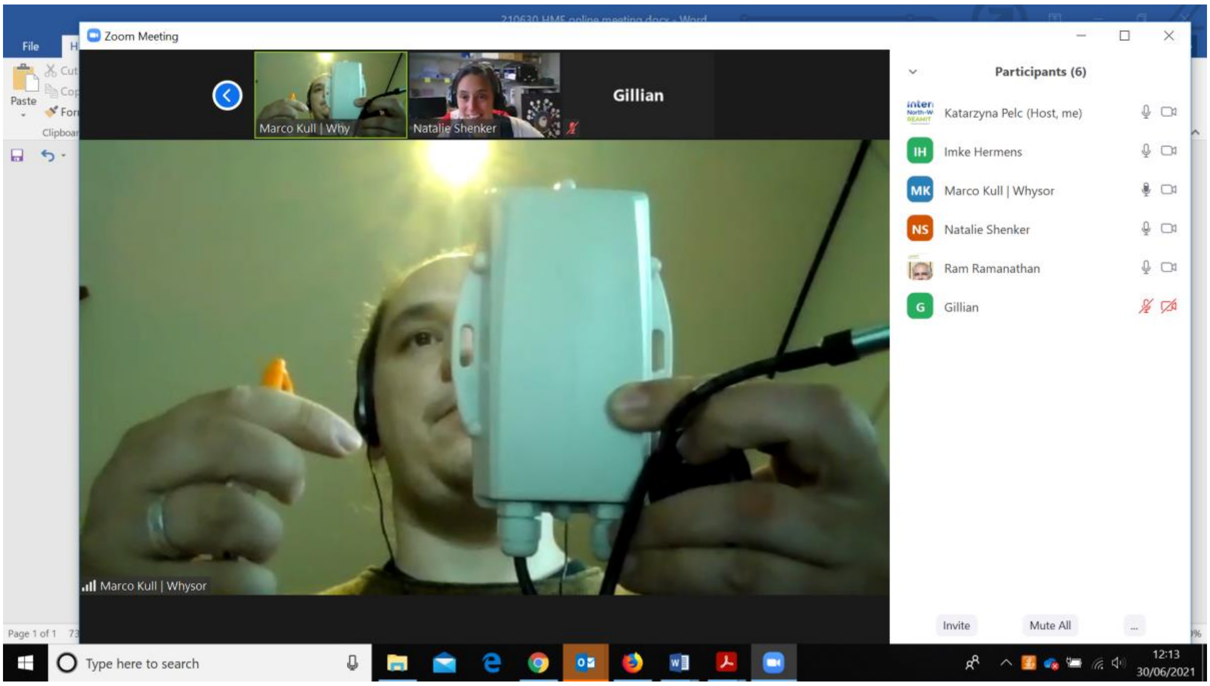



*Figure: Online meeting of the REAMIT partners (University of Bedfordshire and Whysor) with Human Milk Foundation to present the temperature and humidity sensor with GPS locator and accelerometer functions installed in a HMF milk bag.*

*Figure: A logger logging data on temperature, GPS location and acceleration from trips of human milk bags transporting donor human milk.*

In Summer 2022, Whysor created a dashboard which presents data collected from 12 temperature and humidity sensors and 10 binary sensors installed at HMF. Dashboard parameters were adjusted based on input from HMF on temperature thresholds for transported donor human milk. Whysor dashboard is a web-based system and can be accessed from a mobile phone or a computer. It is a webpage and a user can open a browser and navigate to the Whysor dashboard. The dashboard sends alerts when the temperature inside a milk bag raises above the set range. Alerts are sent via email or SMS. Since Whysor does not have a smart phone APP connected to Whysor cloud, in the next steps of this pilot test, an APP will be developed by the REAMIT team to send alerts to HMF via an APP.

## 10.6 The implementation of the pilot test

During the implementation of the pilot test, partners at HMF raised a number of questions to be addressed by the REAMIT team. They included what distances HMF bikers/drivers could handle with the REAMIT technology; and would the REAMIT system work for long distances. For every journey with donor human milk, HMF needed a system that assured that milk was kept in the right conditions (temperature below –15 degrees Celsius) inside a milk bag. HMF needed a system that kept track of donor human milk from the moment it was expressed, knowing they needed to handle 30-50 trips at one time. HMF needed a system that provided information on what happens minute by minute with donor milk during transportation. HMF was keen to see data on how much milk was transported in a milk bag, and whether a milk bag was full or not. Based on this information, HMF may need to use smaller milk bags in the future to improve optimal temperature during transport. The director of HMF confirmed that a system providing all this information would be fascinating for HMF.

*Observations of the REAMIT data analytics team. Focus and boundaries for data analysis for HMF*

In October 2021, the REAMIT dashboard at Whysor presented temperature measurements recorded every 5 minutes (for trips of human milk bags in October 2021). This means that data in REAMIT dashboard is live (it is not only historical data). Dashboard presented no data in November and December 2021 implying that sensors were not sent on trips then.

The IoT system proposed by REAMIT was capable of picking up precisely the time when temperature inside a milk bag raised above the set range, e.g. sensor data collected at HMF on 15th October 2021 between 11.00 AM and 12.00 at noon showed that temperature inside a milk bag increased at that time from –20 degrees Celsius to –11 degrees Celsius. Data for measurement of temperature was of high quality and high integrity, and it was obtained every 5 minutes. Little data pre-processing was involved which confirmed that the collected data was of high quality.

REAMIT data analytics partners looked at the data from sensors and discussed what other data was needed to perform data analytics and develop predictive models. They looked at:

- Glitches in data and observed pattern of glitches
- Journey length and correlated to this, how different routes can affect length of journey
- The volume of milk inside a milk bag
- The kind of alerting system, Systematic Operation Procedures and time-based strategy for external temperature measurement.

The proposed IoT architecture and data analysis process for HMF (process flow chart) is as follows: installation of IoT sensors in HMF milk bags, uploading sensor data to Whysor cloud, presenting IoT data in Whysor dashboard, analysis of data obtained from IoT sensors, developing alerting algorithm, sending alerts via an email, SMS or a mobile phone APP to a designated person at HMF.

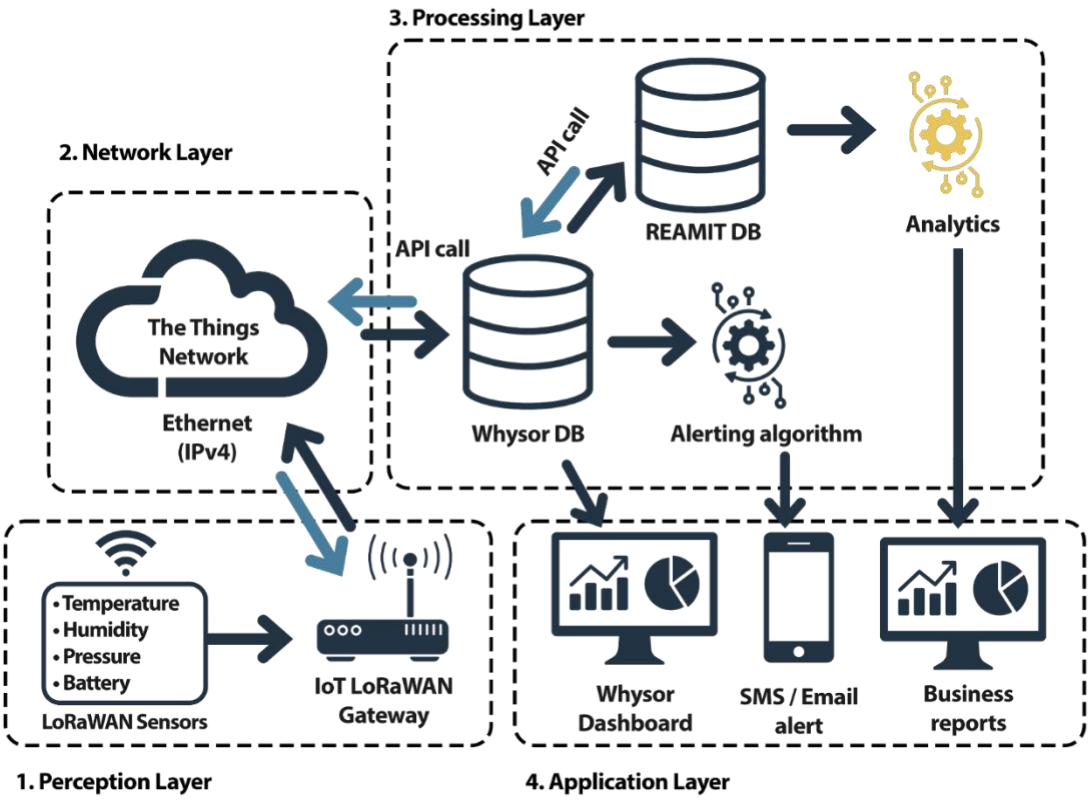



*Figure: The proposed IoT architecture and data analysis process for HMF – process flow chart.*

REAMIT data analytics partners worked closely with partners at HMF and made several observations based on IoT sensor data obtained from HMF:

- Based on reading the current position of sensors inside the milk bag, it was important to determine the optimum position of a sensor inside the milk bag.
- HMF decided that when sensors were sent on trips/when they were back from trips, they would fill in manually a Google Form to gather additional information about the trip. This allowed the REAMIT team to collect more useful data than just the data on where the sensor went and the temperature inside the milk bag. The additional data collected through the Google Form showed the type of vehicle used for milk transportation (car, bike), positions where the sensor was placed in the milk bag and how much milk was inside the milk bag.
- Consequently, data analysis for HMF based on milk temperature data, status of a milk bag data (open/closed) and GPS data, was supplemented by additional data: external temperature and weather conditions data, how full a milk bag was during transportation, and information obtained at the end of the trip (time when the trip was completed and temperature inside the milk bag).
- The REAMIT data analytics team observed that based on about 6 months of data on the weather forecast, some forecasting of weather conditions could be possible. The goal for data analytics would be to build a model based on analytics of real time weather data and historic weather data obtained by IoT sensors installed in milk bags.
- Partners from Ulster presented graphs of data from IoT sensors at HMF in conjunction with the manually inputted values from the Google Form. Their initial ideas for data analysis were as follows: modelling the rate of change of the temperature inside the milk bag after the journey begins, versus for example, the weather outside to predict how long the temperature inside a milk bag can remain within the desired range.

- Partners observed that some interesting things can be seen in data but there was also a lot of inconsistencies in data that would need to be figured out before they could dig deeper in the data.
- Data analytics team have formulated a recommendation for HMF that it may be helpful to use smaller size human milk bags for milk transportation, depending on the volume of milk transported.

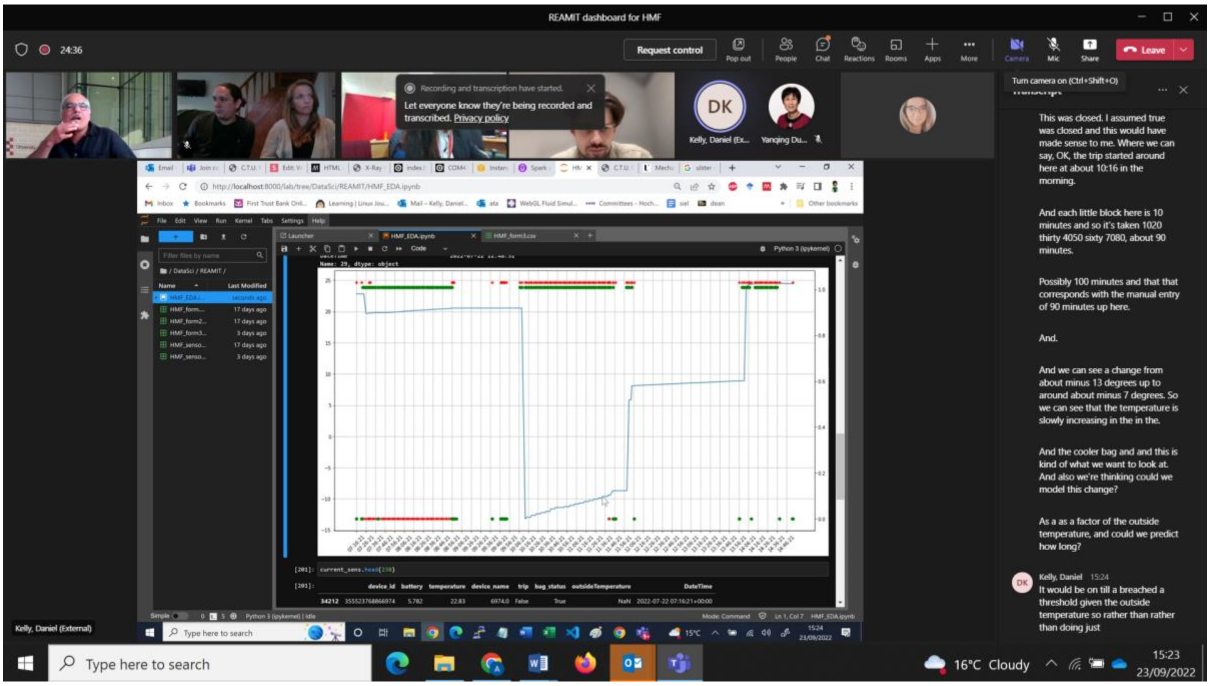


*Figure: An online meeting of the REAMIT partners focused on data analysis for HMF (attended by technical partners at Whysor, data analytics partners at Ulster and the Lead Partner at BED and UEssex).*

Based on obtained IoT sensor data, external weather data and data collected in the Google Form, the REAMIT data analytics team have developed an algorithm for optimal journey length and duration for HMF as well as the alerting system without human intervention.

*Challenges in the pilot test execution:*

- Uploading sensor data to Whysor cloud was the most energy consuming part of data collection process, which led to exhausting batteries and reducing the battery life. To save the battery's energy, the REAMIT technical team proposed disabling sensor alarming functionalities when it was not necessary to send alerts. Partners at Whysor explored two possibilities: using rechargeable batteries (which however was not easy and required certain voltages) and using another type of batteries – Altium. Also, Nathalie from HMF confirmed that obtaining live data every 30 minutes was sufficient.
- The battery life dramatically improved after the trip detection configuration had been applied, since data was recorded only every hour (instead of every 2 or 5 minutes) when the bag was not in transport, and uploaded to the Whysor cloud once every 12 hours (when not in transport).
- In spring 2022, REAMIT technology partners experienced issues with logger availability in the market. Due to COVID, there was lack of chips around the world (while chips are fundamental component of loggers). In consequence, the European suppliers of loggers were out of stock

and could not guarantee when the new stock of loggers would arrive (it would take several months). REAMIT technology partners found the right loggers at a supplier in South Africa and ordered 10 pieces of it. However, the ordered loggers were slightly bigger than the loggers previously installed at HMF.

- Installation of the additional 10 loggers and sensors at HMF made it possible to collect more IoT data for data analytics. However, partners at HMF later on confirmed that the loggers were rather big and heavy and asked the REAMIT team to install smaller and lighter loggers and sensors. However, due to the end of the REAMIT project, installation os smaller and lighter IoT equipment was not possible.

## 10.7 Relationship with the company through the pilot test

In 2021, due to COVID-19 pandemic, communication between the REAMIT team and partners at HMF was through emails and online meetings. As the COVID restrictions started to ease in the summer of 2021, an on-site visit at the premises of HMF took place. On 27th September 2021, partners from Whysor installed two temperature and humidity sensors in the milk bags at HMF. On 23rd May 2022, a second visit of the REAMIT team at HMF took place. During the visit, the REAMIT team attended a tour of HMF; installed 10 additional temperature, humidity and binary sensors in human milk bags; and recorded interviews for the REAMIT documentary. In the final semester of the REAMIT project, two meetings with partners from HMF took place: on 2nd of May 2023 a hybrid meeting hosted by HMF in Harpenden took place focused on the presentation by the REAMIT team of the results of data analytics and the mobile APP for HMF; on 14th of June 2023 an online meeting with HMF partners took place, attended by BED, HMF and a KTP advisor from BED, which focused on developing jointly new project proposals inspired by the REAMIT project (a KTP project for HMF with capital from philanthropy investors, and a COST Action led by HMF).

## 10.8 Communication and dissemination activities

- Presentation of the REAMIT pilot test with HMF at 3rd REAMIT Symposium, UCD, Dublin, Ireland, December 2021.
- ‘The role of food waste in improving sustainability of food supply chain’, University of Essex, UK, May 2022.
- Introducing more formally the REAMIT project and partners to the entire team at HMF, internal team meeting at HMF, January 2022.
- Presentation of the REAMIT pilot test with HMF at 4th REAMIT Symposium, Nantes, France, December 2022.
- Presentation of the REAMIT project and its pilot test with HMF to 8-year-old pupils at a primary school, 17 January 2023, St Albans, UK.
- Promotion of the REAMIT project and its pilot test with HMF at the Business and Management Research Institute Annual Conference, University of Bedfordshire, Luton, UK, 18 January 2023.
- Presentation of the REAMIT project and its pilot test with HMF at ‘Advancing Women in Agri Food Rural Environments’ event, BED, Luton, UK, 27 February 2023.
- Presentation of the REAMIT project and its pilot test with HMF at ‘Sustainable Supply Chains Conference’, London, UK, 10 May 2023.
- Promotion of the REAMIT project and its pilot test with HMF at ‘Private Capital Symposium’, London Business School, London, UK, 16-17 May 2023.

## 10.9 Other best practices and lessons learned

At the beginning of 2021, HMF had one human milk collection hub and operated only in South-East England. They did not know how many collection hubs would be needed in the future. At the end of 2022, HMF already had 4 hubs and 3 were in the pipeline, and they were keen to operate across much wider geographical range. Also, since the REAMIT pilot test started in 2021, HMF started to deliver milk

to hospitals located far away, and started to consider different solutions for keeping milk cold inside the bags transporting milk (e.g. using ice cubes), or using drones for milk transportation.
The REAMIT team agreed that HMF probably offered one of the more interesting opportunities for data analytics because HMF actually had the supplementary labelled data (from the Google Form) collected for the REAMIT team, which made it possible to actually contextualize the data a bit more than doing simple time series analysis.

Data from HMF and this pilot test really show that simply reading the IoT sensor data in isolation is not working. There is a lot of contextual data and contextual information, which are important to get, in order to make the Big Data meaningful. It also shows that we need very close collaboration with the pilot test company to make meaningful the data analysis and prediction models. Installing IoT sensor technology without contextual background makes it difficult to make use of the Big Data. Partners preparing a case study on the data analytics for HMF will have to record these observations as well as the need for close cooperation between the technology partners, the end users, and data analytics partners. Without doing the real test at HMF, the REAMIT team would not know this. You would tend to think that once you install the sensor and read the recordings, you can easily identify patterns. However, the pilot test with HMF shows that this is not the case.

# 11 UK pilot test: YumChop

## 11.1 Presentation of the pilot test company

YumChop is a British-based family-owned company specialising in producing ready-to-eat frozen meals with African flavour and selling them in containers through self-serviced automated vending machines. YumChop also delivers directly to customers' homes through purchases made on website, and through retailers and large organisations too.

YumChop was set up in 2016 by Abi Adefisan and Michael Adefisan, and officially launched in 2018 when the business got the tender with TUCO to supply into universities across the UK through the vending kiosks. In 2019, they started deploying their meals into universities. They also had the NHS approval to supply into hospitals in UK.

The meals are frozen, are free from preservatives and additives. For production, YumChop use a special technique where they flush food, freez it within a very short time, while another team labels it. This technique enables a good shelf life (18 months of shelf life) to preserve the meals and make sure that they still have the same quality from the time that they are frozen all the way to when people eat it.

A microwave is incorporated within the vending machine kiosk which allows consumers to not only get the frozen food but prepare it to eat there too.

In the factory, during the manufacturing process Yumchop ensure stable temperature of the fridge and freezer as well as maximally reduce any chance of temperature drop or increase

An important fact: there was an episode when the temperature in all freezers increased (the freezers must be set at -18 ºC) and as a result, the company lost all the products stored in those freezers.

## 11.2 The company recruitment

The REAMIT team got in contact with Yumchop owners via the Research and Innovation Service at the University of Bedfordshire, UK in autumn 2019. The pilot test with Yumchop started on 21 December 2020 and the University of Bedfordshire (BED) has become the Pilot test Lead.

## 11.2 Issues and challenges faced in terms of food waste by the company

There were three main challenges that REAMIT team along with YumChop was aiming to address in the pilot test. First, to ensure that frozen food is stored in the right temperature in the food factory. Second, to ensure that frozen food is transported in the right temperature from the YumChop food factory to where vending machine kiosks are located (including NHS hospitals) or to private homes (YumChop home delivery service). Third, to provide food fingerprint (i.e. data on the condition in which food produced by YumChop has been stored and transported).

There are different locations in the food factory, different zones, freezers, cold rooms, vending machines, and kitchen fridges. When the temperature inside the freezers increases, the quality of the meals goes down, as well as the safety of the meals becomes an issue. The owners of YumChop were seeking in what ways the sensors could automatically send the relevant data on the temperature to their emails or phones. Thus, the REAMIT team has been looking for controlled temperature and humidity data. Receiving such temperature alerts, could allow the owners of YumChop taking appropriate actions to tackle any potential risk. This would also help reduce the loss of revenue.


## 11.3 The selection of relevant sensors

Whysor specified the equipment needed for YumChop and decided that T° tracking will be the most suitable. The T° will be monitored in the factory, during the transport to the NHS (place where the pilot will take place) to make sure the t° is in the threshold. Whysor selected two types of sensors: ELT Lite (ELSYS) and digital temperature sensor (ELSYS) to be installed.

Regarding the vending machine kiosks, the Ulster and UCD team decided first to install one sensor to see how the signal and connectivity would be affected since the sensor was located in Victoria coach station in London, UK.

## 11.4 The installation of the sensors

Whysor identified which sensors would be the most suitable for YumChop, whereas BED was in charge of the procurement and delivery of the equipment to Whysor's office in the Netherlands for configuration (mid-June 2021).

BED experienced a delay in procuring one piece of equipment (from a company called Alcom in the NL). Since Alcom had only 1 sensor of this kind left in stock (and it would take 3 months to get new supply of sensors), BED asked Alcom to 'reserve' it for BED, as BED finance promised they would be able to action procurement by then (21/06/2021). In June 2021 BED actioned purchase of the equipment.

Fitting of the sensors was one of the difficulties faced during the installation process. Due to the Covid 19-related travel restrictions, they could not have been fitted physically at YumChop. There was a risk involved for sending the sensors by post from Whysor (based in the Netherlands) to YumChop.

Installation of sensors at YumChop's factory was planned for summer 2021. Whysor planned a visit to UK in the first half of August 2021 and would combine it with visiting YumChop's factory. Eventually, partners from Whysor managed to visit YumChop on 28 September 2021 and installed 10 sensors and gateway.

1. Zone B – Freezer 1
2. Zone B – Freezer 2
3. Zone E – Freezer
4. Zone E – Fridge
5. Zone D – Cold room freezer
6. Zone D – Cold room fridge
7. Zone D – Fridge
8. Container cold room (= freezer)
9. Green Kitchen Fridge
10. Vending Machine (= freezer)

Abi Adefisan, Michael Adefisan and Francis Odudimu from YumChop were present during the visit.

Whysor developed a dashboard for YumChop. The company owners have access to the dashboard, they have all the permissions to change things by themselves in the dashboard. Weekly reports generated by the dashboard for Whysor for each fridge and freezer provide relevant temperature data.

The dashboard shows temperature in all zones at the company, where sensors have been installed. It can be set according to YumChop's needs (scales, colours, etc.). When a sensor measures temperature of -15 ºC (or higher) two times in a row, YumChop gets an alert. Partners at YumChop wanted to access the dashboard and modify it according to their needs too. Whysor provided the credentials to Yumchop and would also check if Michael can get the rights to change his own dashboard.

The sensors keep sending the information on the temperature levels inside different zones. There are different temperature ranges for different zones, and when the temperature goes above this range, the alerting system sends an alert to YumChop.

On 18 November 2021, an online meeting on 'REAMIT Dashboard for YumChop' took place, organised by Whysor and attended by Abi Adefisan and Michael Adefisan, co-founders of YumChop, Whysor and BED. The dashboard for YumChop shows temperature in all zones where sensors have been installed (below-15 ºC, or higher, two times in a row, an alert is triggered). Abi also confirmed that they set up their freezer at -24 ºC; and that they do not need temperature at -30 ºC. Too low temperature means too much energy consumption for YumChop.

Abi confirmed that all sensors installed at Yumchop's food factory worked well. Temperature in one freezer raised from -30 ºC to -15 ºC. This lasted for some hours and the sensor did not pick up on it. The temperature dropped again to -20 ºC.

Imke made a weekly report for the sensors located in the freezers and this has provided useful data for the company to be used daily, including, to fulfil the legal requirements.

## 11.5 The implementation of the sensors

Anomalies in temperature cause some of the problems (and additional costs) for YumChop. In many cases, these anomalies need to be fixed manually, and the automated systems may not help. For example, if somebody has opened the door, there is no way for the machine to close the door.

In January 2021, there was a  break in obtaining temperature data from YumChop.

Between January and April 2021, there were different alerts sent to Abi, the co-owner of Yumchop, but Whysor managed to resolve this issue. On 25 May 2022, partners from UCD, UU, NTU and BED visited the YumChop factory to look more closely at the problem.

An initial data analysis showed that there were glitches in the data assessed and the REAMIT team tried to identify the patterns. One of the possible explanations was that when there were spikes in the temperature, the temperature was raising at a constant rate. Thus, a pre-emptive alert mechanism could be implemented to inform YumChop of possible spikes in the future.

In January 2022, there were some issues with false alerts sent and once Abi received an alert for one of the freezers. Imke from Whysor assumed that maybe the sensors were not installed correctly as temperature measurements of the fridge were providing other temperature than theirs. She communicated with the co-owner of Yumchop and asked to take a picture of the freezer exterior as a whole and to take a picture (or video) of the sensor and how/ where it is installed inside the freezer.

Since February 2022 internal meetings took place of REAMIT data analytics partners, focused on data analysis for YumChop.

## 11.6 Relationship with the company through the pilot test

Overall, the relationship with the company has been good. YumChop appreciates being involved in the REAMIT project. Unlike most companies in the project that wish to remain anonymous, YumChop has agreed that the consortium uses their names in REAMIT communication materials. This, certainly, helps promoting the REAMIT project and increases its visibility.

Moreover, Abi, the co-founder of YumChop, confirmed that they were keen to expand the pilot test and install the sensors in vending machines located at universities and hospitals, as well as in vans delivering YumChop food to customers' homes and Sainsbury's supermarkets. Also, YumChop agreed to provide data for Life Cycle Assessment (LCA).

## 11.7 Communication and dissemination activities

Overall, the communication with the owners of YumChop has been good and its managers expressed an interest in installing more sensors e.g. in the vending machine kiosks at London Victoria Coach station.

To promote the pilot test, the REAMIT partners have undertaken the following actions:

In March 2022, a poster on YumChop was developed by NTU with inputs from partners and shared with Abi and Michael Adefisan, the owners of YumChop.

In March 2022, a case study on Yumchop was shared with Abi and Michael Adefisan: 'Some experiences on the use of digital technologies to reduce food waste and improve operational efficiency of a frozen food company – The case of Yumchop Foods in the UK'. Purpose of this case study was to use it for university students as well as develop research publications in the future.

The REAMIT Communication team has promoted the YumChop case study and our joint activities in the newsletters too (see for example, September 2022 and March 2023 REAMIT Newsletters).

Collaboration with YumChop has been mentioned in our communication through social media too (including Twitter and LinkedIn).

Moreover, one research paper has focused the YumChop pilot test, and has been published in the *Sustainability Journal*: "Adapting Digital Technologies to Reduce Food Waste and Improve Operational Efficiency of a Frozen Food Company—The Case of Yumchop Foods in the UK".

## 11.8 Other best practices and lessons learned

Maintaining regular communication with the company owners, being responsive to their concerns and needs helped building a trusted working relationship with YumChop. As a result, the company was interested in taking an active part in the research (participating in interviews, permitting filming a documentary video at YumChop's premises) as well as in further collaboration with the research team and expanding the pilot test to the vending machine kiosks.

For a potential interview or meeting with a company involved in a research project, it might be also good to send questions to the company involved in the research project in advance and, ideally, to split them in smaller chunks. This will help maximize the preparedness of the staff to discuss issues in more detail. This was the case of YumChop, when their owners were approached about some specific data relevant for LCA. Research team should exhibit a flexible approach towards the company's owners and address their concerns with attention.

# 12 Northern Ireland laboratory testing: Ulster University in collaboration with FreshDetect GmbH

## 12.1 Presentation of the pilot test company

FreshDetect GmhH manufacture the FreshDetect BFD-100, a handheld non-invasive fluorescence spectrometer device that operates at an emission wavelength of 405nm. The FreshDetect device was initially designed for monitoring the quality of meat products by determining bacterial contamination through the estimation of the total viable count, which refers to the number of viable microorganisms present in a sample. However, in the REAMIT project the FreshDetect device has been the subject of exploration to determine its applicability in assessing the freshness of other household food items that are prone to spoilage.

## 12.2 The company recruitment

FreshDetect GmbH initially participated as a partner during the application phase of REAMIT in 2018. However, between application submission and application approval, they encountered financial difficulties and eventually filed for bankruptcy. Despite this, Matthias Heiden, the original contact person from FreshDetect, decided to acquire the assets of the company and remained interested in product testing and development. Due to the bankruptcy, FreshDetect was unable to provide any additional resources for the project apart from the equipment and some consultancy time offered by Matthias. As a solution, Ulster University, a partner in the REAMIT project, agreed to take on the budget originally allocated to FreshDetect GmbH. They would then proceed with the research on the handheld spectrometer, receiving support from Matthias in the process. This arrangement allowed the project to continue despite the challenges faced by FreshDetect, ensuring that the research and development objectives could still be pursued with the involvement of Ulster University and Matthias Heiden.

## 12.3 Issues and challenges faced in terms of food waste

In this pilot, the goal was to expand the application of FreshDetect beyond meat products and evaluate its effectiveness in determining the freshness of whole milk (2%). The motivation behind this was fuelled by the removal of use-by dates on milk by some UK supermarkets, promoting alternative methods like the "sniff test" for determining milk spoilage. This pilot sought to explore the potential of utilising the portable handheld spectroscopy device as a quantitative tool for measuring milk quality. By doing so, it aimed to reduce the reliance on subjective olfaction techniques and potentially pave the way for the introduction of handheld spectrometers as a commonplace tool in households, in turn offering consumers a more reliable and convenient method for assessing the freshness of their milk.

The objective was to examine the relationship between the fluorescence signals emitted by milk and attempt to correlate it to its freshness status.

## 12.4 The selection of relevant sensors

Since the collaboration was with FreshDetect GmbH, the selection of sensors was limited to the handheld device they offered. This was the FreshDetect BFD-100, a handheld non-invasive fluorescence spectrometer device that operates at an emission wavelength of 405nm.

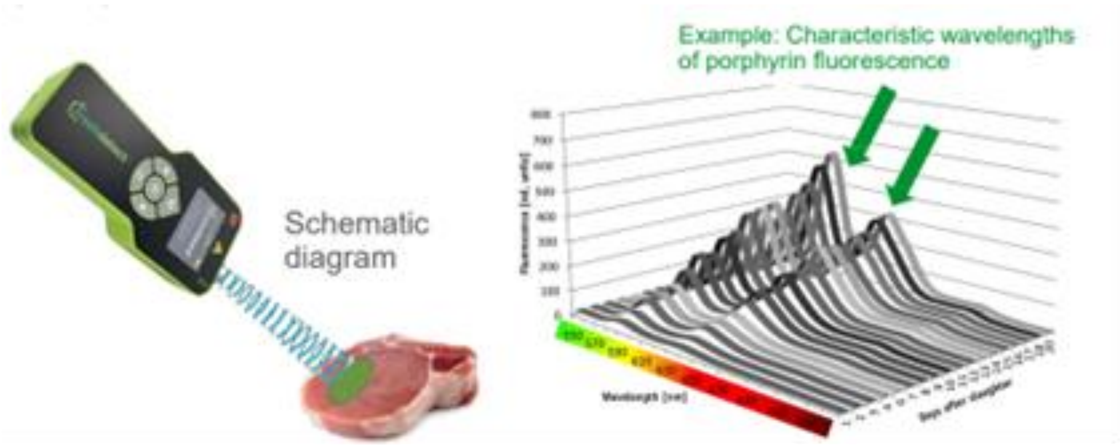



*Figure 55: FreshDetect BFD-100*

The decrease in pH is one of the indicators of milk spoilage. Fresh milk typically has a pH of around 6.6 to 6.8, which is slightly acidic. As spoilage progresses, the pH can drop significantly below this range, indicating that the milk has become more acidic. The increased acidity not only affects the taste and sensory qualities of the milk but also creates an environment that is unfavourable for the growth of other microorganisms. The acidic conditions help to inhibit the growth of spoilage-causing bacteria and may contribute to the characteristic sour taste and odour associated with spoiled milk.

Since it is known that lower pH levels are associated with milk spoilage, researchers sought to link the spectra obtained by the FreshDetect to a measurement of pH. In order to obtain accurate and consistent pH measurements, the Thermo scientific Orion Star A215 pH meter was chosen. This laboratory grade pH meter offered the ability to log pH measurements using a provided user specified time increment, ensuring that the milk quality degradation could accurately be monitored. The device offered USB communication allowing the measurements to easily be exported and transferred to a computer, enabling the researchers to map the pH data to spectra obtained by the FreshDetect at the same timestamp.


*Figure 56: Thermo Scientific Orion Star A215*

## 12.5 Initial findings / analytics

The results of the spectra were discussed with analytical chemist partners at University of Nantes, where it was discovered that the main spectra peak produced by the FreshDetect was Riboflavin, a water-soluble vitamin which is a key component of milk.

Figure 57 presents the initial results, which show that as the milk ages, both the pH of the milk and Riboflavin levels obtained from the FreshDetect spectra decline. This is thought to be primarily due to the chemical instability of riboflavin under acidic conditions. Riboflavin is sensitive to pH changes, and its stability is influenced by the acidity or alkalinity of the environment. Researchers are continuing to work on the basis of these preliminary results and hope to collect a large milk dataset, enabling the production of a regression model to classify the age of the milk and thus its freshness based on Riboflavin levels. This exciting research demonstrates the capability of the FreshDetect as a food quality assessment tool outside of its original use in the meat industry, opening many other avenues for future research.

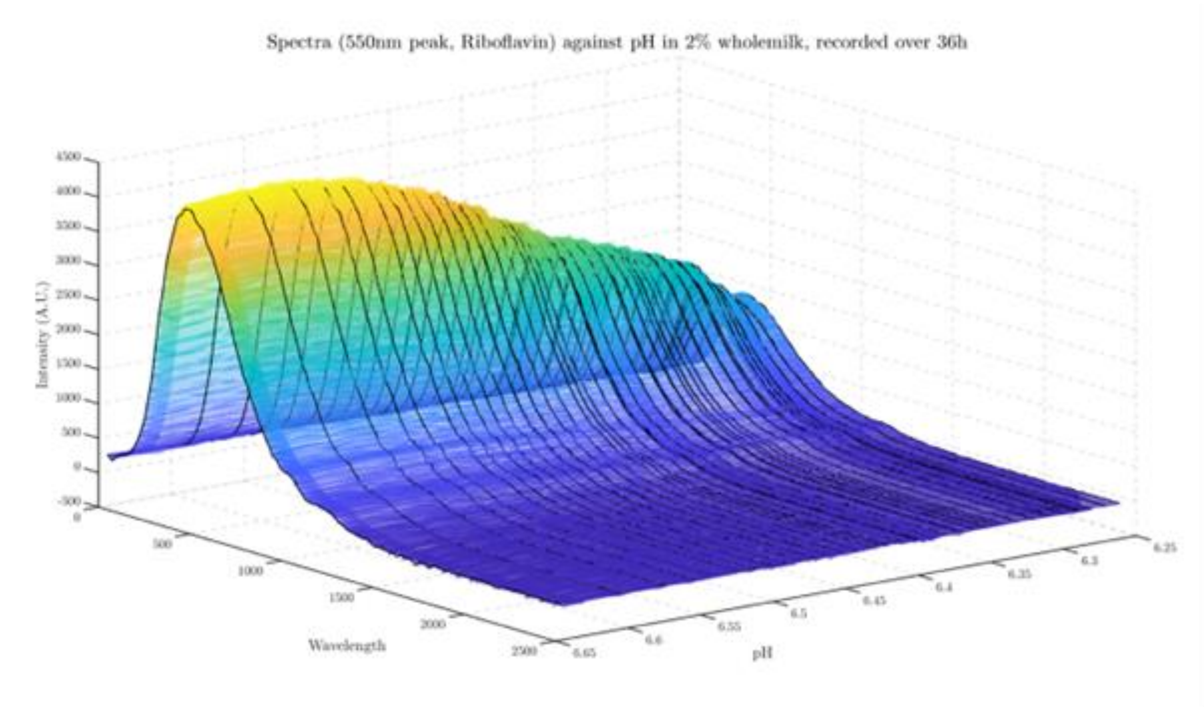



*Figure 57: Spectra (550 nm peak, Riboflavin) against pH in wholemilk, recorded over 36h.*

## 12.6 Relationship with the company through the pilot test

Matthias Heiden remained available to consult to the REAMIT partners throughout the project and was very cooperative in scheduling meetings and providing advice when asked. Matthias also advised on MSc project research which used the FreshDetect. Matthias extended the loan agreement of the FreshDetect by 1 year to account for the project extension, allowing researchers to continue with their experimentation.

## 12.7 Communication and dissemination activities

FreshDetect research was first documented in the newsletter in April 2021, showcasing initial testing on meat products. A second newsletter piece documenting the results from the milk quality feasibility study appeared in the June 2023 newsletter. Additionally, the FreshDetect was used for MSc research at the University of Bedfordshire during the project, investigating the devices use for both bacteria monitoring in meat and strawberry freshness. The research appeared in the MSc thesis.

A journal article is planned on the milk quality study in later 2023.

## 12.8 Other best practices and lessons learned

To ensure consistency and obtain a reliable spectra training set, it is crucial to maintain a consistent distance between the FreshDetect device and the sample during each scan. In order to facilitate this, a custom 3D printed casing was specifically designed, providing a fixed and replicable scan distance for the FreshDetect device. By using the custom casing, researchers can maintain a standardised scanning procedure, which improves the accuracy and reliability of the spectra obtained for training and analysis.

The laser integrated into FreshDetect has a narrow emission range centred at 405nm, which was suitable for its initial purpose of determining total viable count (TVC) in meat products. However, this limited range poses challenges when expanding the device's use to other applications. Specifically, at 405nm, the laser can only excite Riboflavin in milk, while other chemical properties undergo changes during spoilage that cannot be detected within this spectral range. Gaining insights into these additional properties could provide researchers with a deeper understanding of the factors contributing to milk spoilage and potentially lead to the development of a more informative model. To capture information about these properties, it may be beneficial to replace the laser with a broader range LED, allowing for a wider range of chemical analyses in milk samples.

# 13 The REAMIT Consortium

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| University of Bedfordshire | The University of Bedfordshire is the lead partner of the REAMIT project. They have expertise in making business sense of big data and internet of things technologies, applied to agriculture, aquaculture and other sectors. |
| images & réseaux | Images et Réseaux is an ICT Cluster in western France , and we are focused on cores digital technologies (5G & next generation infrastructures, big data and AI, immersive & interactive content, cyber physical system, digital trust, and photonics) in 5 sectors (health, agriculture & farming, digital fab & services, digital territory, and digital entertainment) https://www.images-et-reseaux.com/ |
| UCD DUBLIN | University College Dublin (UCD) is Ireland's premier university, with over 24,000 students and a research budget in excess of €100 million per annum. The UCD members have expertise in food engineering, have developed IoT based sensors (e.g., the CyberBar system) and lead life cycle assessment modelling for the analysis of environmental impacts of a range of production systems. |
| UNIVERSITÉ DE NANTES<br>GEPEA | The GEPEA laboratory of University of Nantes participates mainly in the development of optical sensor for REAMIT project. The laboratory has solid scientific skills in optical biosensors applied to food and environmental fields.<br>https://www.gepea.fr/ |
| LEVSTONE | Levstone Ltd a software house specialising in high-security, cutting edge mobile software and cloud big data solutions. Levstone are winners of InnovateUK (Gov) research projects. Our solutions are used in logistics, transportation, and health and social care for vulnerable citizens. We focus on real-time data acquisition (inc. IoT sensors), data privacy and ensuring data authenticity. |
| NOTTINGHAM TRENT UNIVERSITY | Nottingham Trent University is one of the leading higher education institutions in East Midlands, UK. We are liaising with local businesses for our curriculum enrichment and practice-based education. Our primary activities in this REAMIT project are dissemination of results to wider community and communication to internal & external stakeholders through various media. We will also be involved in implementation of IoT technology in agri-food supply chains of local food businesses. |
| WHYSOR | Whysor's main activities are in the Internet of Things and Big Data area. They connect IoT devices to the cloud, by providing a long-range (LoRa) infrastructure for the Internet of Things. For the REAMIT project, Whysor will work with pilot tests in all five countries to collect data from sensors and put them in the cloud and also work on analytics along with other partners. Next to being a broker we will be providing dashboarding functionality to view the gathered data in realtime as well as the ability to generate alerts based on that data. |

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| | Munster Technological University (MTU) (previosuly known as Insitute of Technology, Tralee) has at its core expertise in electronic and mechanical hardware, software, IoT and data analytics. This expertise is applied across a large range of verticals including manufacturing, agriculture and food sectors. MTU has previously developed sensor platforms for environmental monitoring and analysis in the food supply chain through their involvement in the Life+ funded Freshbox project. www.imar.ie |
| | SenX is the software developer and publisher of Warp 10, an Open Source solution to manage and to analyze data from sensors / IoT. Warp 10 is based on a Geo Time Series technology and propose a Time Series database and a library og more than 900 data analytics functions in an horizontal, performant, neutral, secured and industrial perspective. |
| | The University of Ulster is a partner of the REAMIT project. They have expertise in sourcing and developing sensors as well as intelligently analysing data from sensors with applications in agriculture, health, tourism and other sectors. |

# 14 Contact

Website: www.reamit.eu

#reamit4nwe

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