WP T1 - Deliverable 3.1

Working prototypes using sensor technology

Improving Resources Efficiency of Agribusiness supply chains by Minimizing waste using Internet of Things sensors (REAMIT)

Interreg North-West Europe
REAMIT

REAMIT

Working prototypes using sensor technology

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1 Introduction

The aim of this document is to present the different sensors used all alongside the pilot implementation. It'll provide an overview of the sensors and scanning technologies complemented with traditional sensors.

This document will present the sensors used for each pilot giving a complete overview of the technical aspect and the data flow generated to be sent to the big data server (under WP T2 "Big Data integration and applications to reduce food wastage" responsibility).

For some pilot an adaptation of the sensors or gateway to reach the cloud has been mandatory to fit results expectations and to take into account the environment where the sensors are installed: constraint linked to the temperature, vibration, network coverage…

2 Dutch Pilot

2.1 Sensor technology used:

Description and explanation of the technology chosen

For the Dutch pilot we chose traditional sensor technology.

Sensor

REAMIT needed to find a solution which would allow real time data upload while the sensors were moving in trucks. We chose sensors with LoRaWan connectivity, because the Netherlands have a LoRaWan network from provider KPN, that covers the total country.

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).

The Elsys EMS sensor costs approximately € 65,- / £ 57 (March 2023).
3.6 V AA Lithium batteries cost approximately € 4,- / £ 3,50 (March 2023).

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

Figure 1 Interior of the EMS sensor

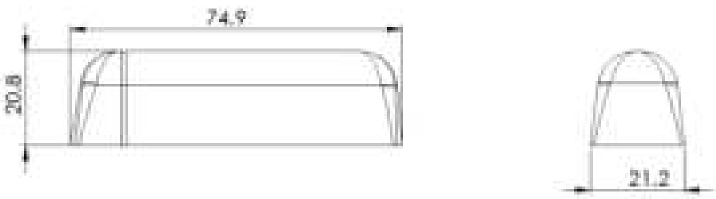


Figure 2 Size of the EMS sensor

List of the experiments undertook before test in real conditions

<u>First testing period:</u>

In July 2021 the REAMIT team installed 4 sensors inside 2 cooling boxes in one of the fulfilment centers of Picnic in the Netherlands. The sensors were installed at the bottom of the box and on the top to test what was the best position to install the sensors in the box. Also, the type of adhesive (glue, kit or tape) had to be defined, because we had to stick sensors made of hard plastic to the box made of styrofoam. For the first testing period two different types of glue were tested: double sided sticky tape, that was provided by the manufacturer of the sensors and special flexible adhesive sealant.

Figure 3 Testing of position and adhesive

After the first testing period we defined the best position for the sensor to be installed, was at the bottom. This because heavy groceries caused immediate damage to the sensors installed on the top of the box. The double-sided tape provided by the manufacturer seemed sufficient for installing the sensors at the bottom of the box.

Second testing period:

For the second testing period, 16 more sensors were self-installed by Picnic inside the cooling boxes, using double-sided sticky tape, in July 2021. The sensors were installed at the bottom of the boxes. In the beginning of August, we evaluated the incoming data and there were no issues at that time.

In September 2021, the REAMIT team noticed that in a few weeks' time less and less sensors were connected. Evaluation with Picnic made clear that the original housing of the sensor was not durable enough to withstand the heavy forces of groceries inside the box. Because the housing broke down, the technology inside the sensor was exposed to cold, moist and were not protected to the forces of the groceries. This caused all the sensors breaking down.

Figure 4 Broken sensor housing

Figure 5 Example of heavy groceries in a cooling box

20 new sensors were purchased and the REAMIT team developed several prototypes of 3D-printed flexible rings to better protect the sensor. Due to the flexible rings the sticky tape, provided by the manufacturer was unusable. Therefore, the team had to find another solution to stick the sensors inside the box. REAMIT-partners at Whysor experienced with different types of glue, kit and sticky tape.

Figure 6 Development of protective rings

<u>Third testing period:</u>

For testing period 3 10 sensors were installed with 2 protective rings per sensor, in December 2021. With these protective rings the sensor housing was better protected, however in a period of 4 months the sensors all broke down again.

Figure 7 Status of working sensors in April 2022

After evaluation with Picnic in March 2022, the sustainability of the housing was addressed as the biggest issue. Next to that, the REAMIT team had to find a solution for the adhesive to be used, that had to be suitable for sticking the hard plastic sensor to the box made of Styrofoam, and still be able to maintain the sensor (e.g. changing batteries).

In May 2022 a part of a cooling box was sent to Whysor by Picnic, to be able to test with real materials.

In August 2022 the REAMIT team at Whysor was ready with the design of a new flexible protection of the housing. Different types of adhesive were tested. In the design of the protection of the housing the team took into account that changing the battery of the sensor remains an easy task.

Figure 8 Adjustment of protective rings

<u>Fourth testing period:</u>

In February 2023 10 sensors with new designed flexible protection of the housing will be installed at Picnic by the REAMIT team at Whysor for testing period 4. We will use BISON PolyMax High Tack glue to fix the sensors in the boxes.

Implementation of the prototype with pilot tests

This prototype was used for implementation with the following pilot tests:

- Picnic in the Netherlands

During the testing with this sensor, we encountered the following difficulties:

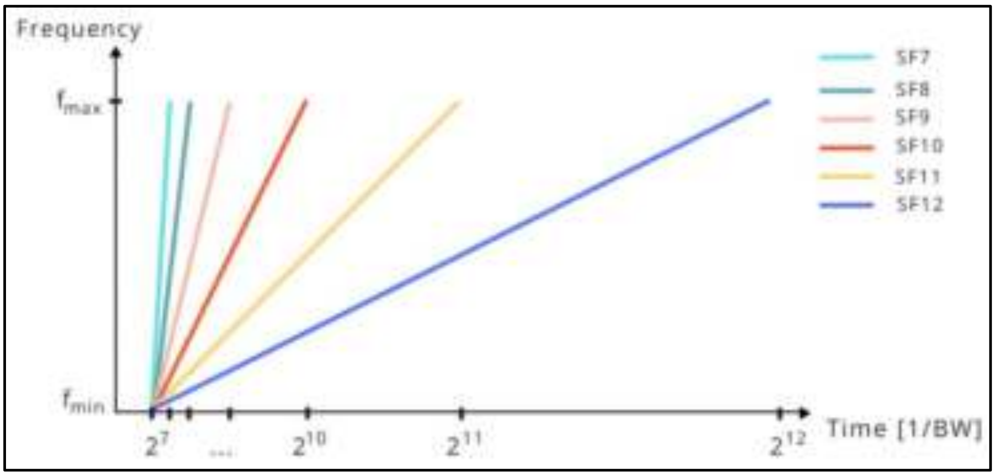
1. Protecting the sensor when the boxes are filled with groceries, has appeared to be challenging, due to the frequency of handling and the impact of heavy groceries.
2. The tracing of sensors that are not working needs more research because of the complexity of the Picnic box routing method.

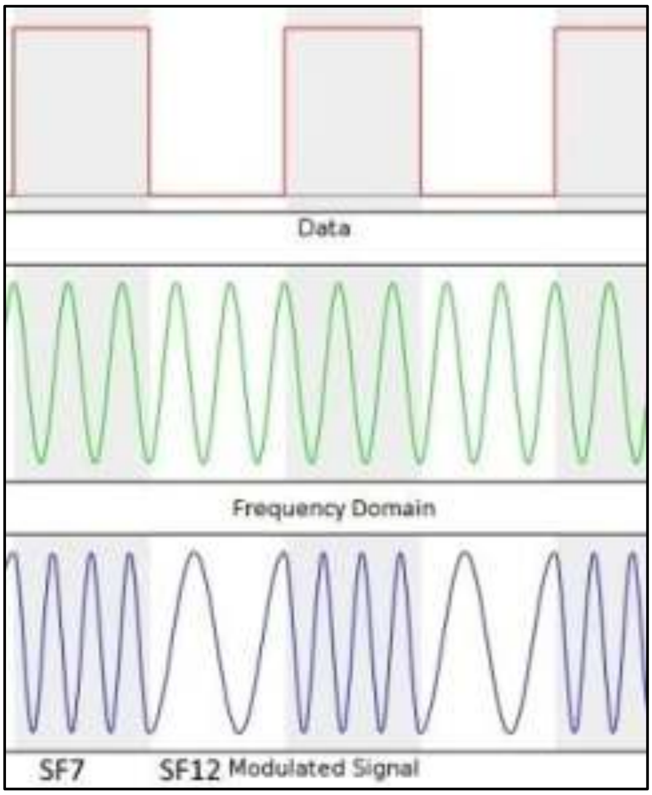
Battery Life.

The sensor of choice runs on 1 x 3.6 V AA Lithium battery, with an expected battery life of up to 10 years, according to the manufacturer (depending on configuration and environment).

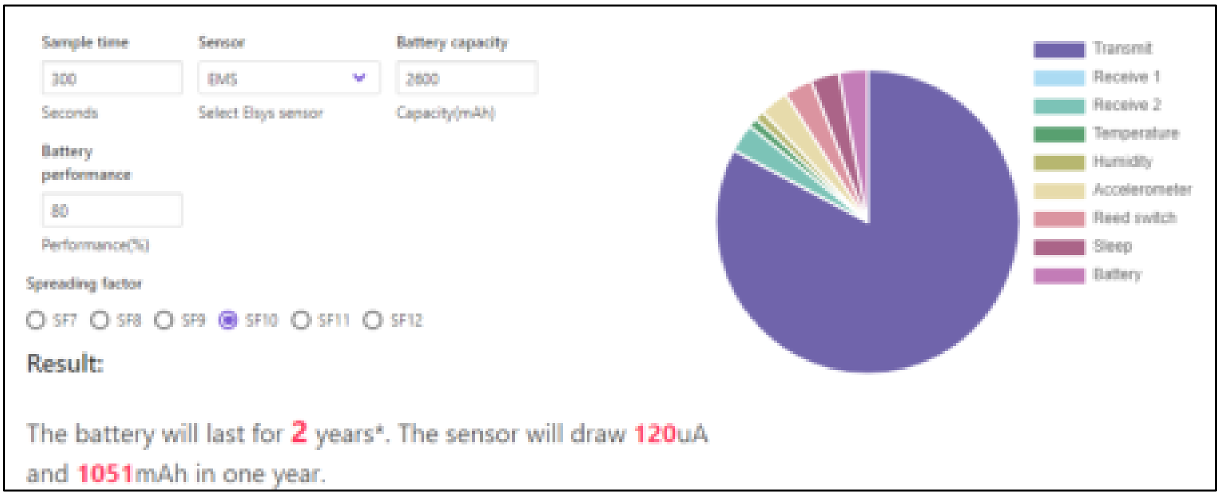
The sensors in this pilot test are configured to send data every 10 minutes. A lower transmission speed has been chosen because there is no consistent signal quality in the trucks. Even with the current configuration of the sensors, battery life is expected to be 1-2 years.

For this pilot we chose spreading factor 12 (SF12)





We calculated the expected battery life of the sensors:



Research signal quality:

This is based on an average Spreading Factor (transmit quality) of 10. We based this on the quality of messages from the sensors from 7 days.

This estimate assumes a sampling time of 5 minutes.

- Best case (SF7) batterylife is 6.2 years.
- Worst case (SF12) batterylife is 0.5 years.
- In practice, the batterylife is 2 years.

2.2 List of the equipment deployed in the pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Elsys (Sweden)	EMS	Measurements of Temperature and Relative Humidity

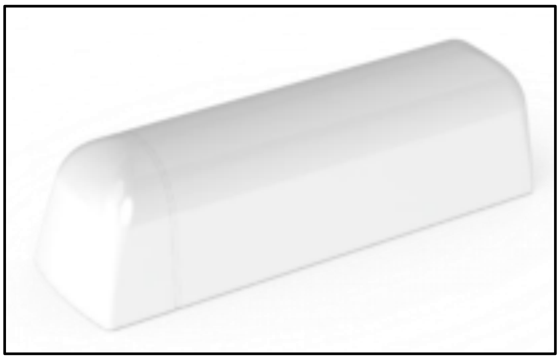


Figure 9 EMS sensor (Elsys, Sweden)

3 Luxembourg Pilot

3.1 Sensor technology used:

Description and explanation of the technology chosen

For the Luxembourg pilot we chose traditional sensor technology.

Logger

REAMIT needed to find a solution which would allow real time data upload while the sensors were moving in trucks. We chose loggers with cellular connectivity because these loggers also include the feature of detecting whether a truck is moving or stationary (trip-detection). 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 I analog and digital inputs allowing for a range of sensors to be configured to best suit the needs of the application.

The Digital Matter Eagle loggers are equipped with intelligent firmware which is able to detect whether a logger is moving (in a trip) or not. The sending and measuring frequency is increased when the loggers are moving.

This ensures maximum data accuracy while also making sure the battery life stays optimal. The Digital Matter Eagle loggers' intelligent firmware is able to store measurements locally, and transmit the data periodically e.g.: Measure every 20 minutes and transmit every 6 hours. Also, when the signal quality is poor and a transmission cannot be completed successfully, the Digital Matter Eagle loggers will try again the next transmission. The loggers are also configurable over the air, so changes to measuring and sending interval can be made on the fly.

The costs of the Digital Matter Eagle logger are approximately 156 USD / € 144 / £ 127 (March 2023).

Sensor

Biogros wanted to be able to monitor both temperature and humidity in trucks, and in warehouses. For this, we selected the T9602 T/RH I2C probe by manufacturer 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.

The costs of the T9602 T/RH I2C probe are approximately € 50,- / £ 44 (March 2023).

List of the experiments undertook before test in real conditions

- Connectivity tests: In November 2021 two sensorunits (with logger "Falcon") were sent to Biogros to test the cellular infrastructure in Luxembourg. The sensors were installed inside the warehouse, the trucks while on the move, and at three growers over a period of 2 months. In January 2022 the connectivity tests had been completed. Data were coming in without problems and connectivity to the cloud via the 4G network was never an issue.

- Trip detection: Trip detection is the ability of the sensor to detect, using GPS, whether a sensor is stationary or on the move. Using this information, the settings of the logger can be adjusted for the different modes of movement: the data can be sent with a lesser frequency when a sensor is not moving, thus sparing battery lifetime. During the testing period sensors were installed inside the car of several Whysor employees and a REAMIT partner to test the trip detection of the prototype. This test was conducted in the Netherlands, Germany and the United Kingdom.

Implementation of the prototype with pilot tests:

This prototype was used for implementation with the following pilot tests:

- Biogros in Luxembourg
- HMF in the United Kingdom
- Musgrave in the United Kingdom (with the addition of an extra Temperature sensor)
- Yumchop vending machines (to be installed in February 2023).

Very little difficulties were encountered during sensor installation and the adaptions carried out. 7 loggers and sensors were self-installed at different sections of the Biogros warehouse, at 3 farmers’ warehouses and inside 7 trucks, by a Biogros technician, without any challenges.

Figure 10 Sensor installed in Biogros warehouse

Battery lifetime: 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. 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.

Figure 11 Extending battery life from 2 months to 8 months

Trip detection: For the sensors inside the trucks a trip detection algorithm was developed based on accelerometer measurements and GPS data reported by the Eagle logger. A trip is reported if motion is detected by the accelerometer and if the GPS coordinate has changed from the previous reading. After a trip is detected, the sensors will start measuring temperature and humidity every 5 minutes and send the data every hour. Out of a trip the sensors measure every 2 hours and send data every 4 hours. Alerts are not sent when the truck is out of a trip. This algorithm allows the system to sleep when trips are not being performed to conserve battery life, as well as avoiding sending false alerts while trucks are parked overnight.

3.2 List of the equipment deployed in the pilot:

Figure 12 Digital Matter Eagle logger

Figure 13 Amphenol Advanced Temperature and Humidity sensor

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Digital Matter (South Africa)	[Eagle logger]	Upload real-time data, Trip detection
Amphenol (USA)	[T9602 T/RH sensor]	Measurements of Temperature and Relative Humidity

4 Northern Irish Pilot with Musgrave

4.1 Sensor technology used:

For the pilot with Musgrave Marketplace we chose traditional sensor technology I.e. temperature and humidity monitoring. As documented above, the Musgrave pilot used the same technology that was developed for Biogros, i.e. a Digital Matter Eagle logger with a T9602 Temperature / Humidity probe.

However, because Musgrave operated chill / freeze dual zone vans, they wanted to be able to monitor the ambient temperature of both these areas in parallel. This meant adding a second probe to the sensor setup.

Implementation of the prototype with pilot tests:

For the second temperature probe, the popular one-wire DS18B20 was selected. This sensor has often been used in the literature for temperature monitoring IoT solutions, especially applied to the agri-food supply chain. While the probe only records temperature and not humidity, it is known that at below freezing, the humidity is much less related to the perishability of the food compared to chill foods. Therefore, the second probe would be used for monitoring the freezer since temperature is the important parameter for quality assessment, while the T9602 would be used in the chill zone of the van since both temperature and humidity can affect the quality of the products stored there.

The DS18B20 sensor needed to be prepared for installation in the logger. One caveat of selecting the DS18B20 on a cable run >2m (required for the intended installation location) 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 Pololu 2119 was selected and added to each of the DS18B20 probes.

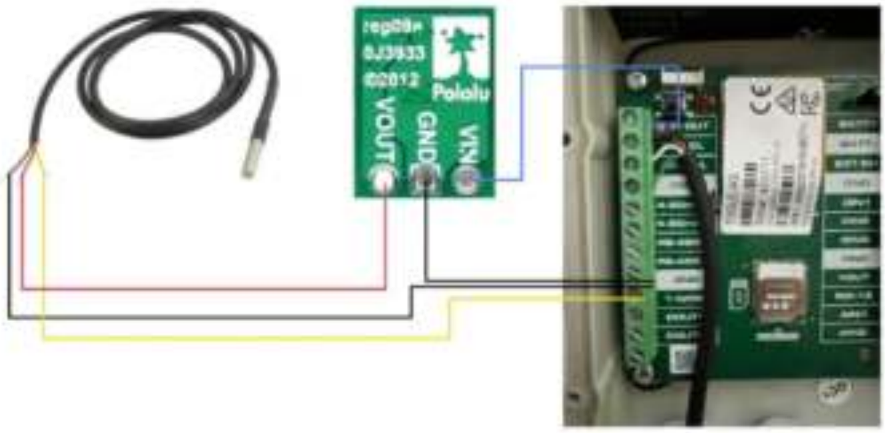


Figure 14: Wiring diagram to add the Pololu 2119 and DS18B20 to the Eagle logger.

Firstly, a hook up wire is soldered to VIN of the 2119 and connected using the screw terminal of 3.3V out. Another wire is soldered from GND of the 2119 and added to the GND screw terminal. The VIN of the DS18B20 (red wire) is soldered into VOUT of the 2119. The black GND of the DS18B20 is added to the GND screw terminal of the logger. The yellow wire from the DS18B20 is added to the 1-wire screw terminal of the logger.

Battery preservation

The logger's 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 15visualises 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.

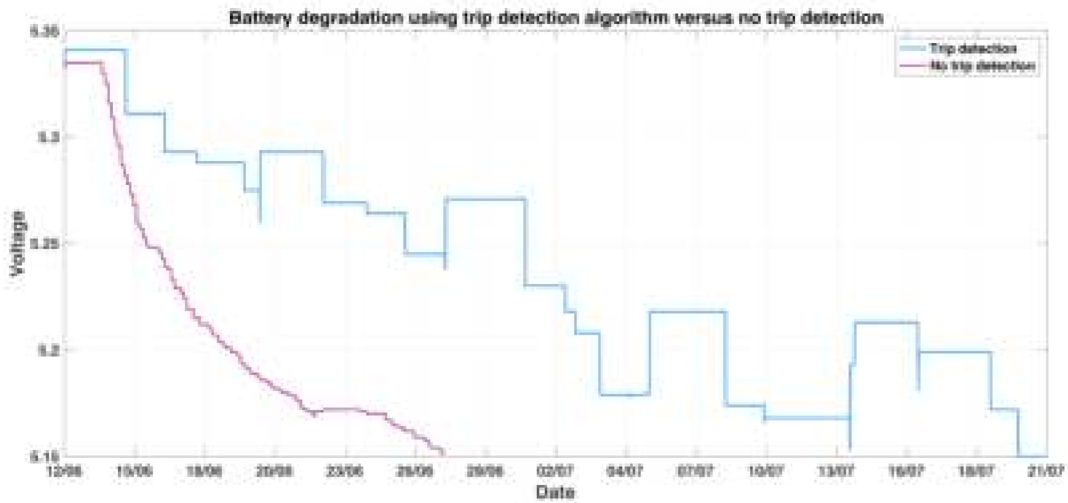


Figure 15 Battery degradation

The difficulties encountered during sensors installations and the adaptations carried out for each of them:

Sensor location

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:

Figure 16: Initial freeze-zone sensor position on roof of van (left), and right, mounting location and method of the IoT logger.

Figure 17: 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.

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. Note also 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 17 shows the repositioned sensor locations.

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.

4.2 List of the equipment deployed in the pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Digital Matter (South Africa)	Eagle logger	Upload real-time data, Trip detection
Amphenol	T9602 T/RH sensor	To measure temperature and humidity
Maxim Integrated	DS18B20	To measure second temperature (different zone in van)
Pololu	2119 voltage regulator	Boost Eagle supply voltage from 3.3V to 5V to power DS18B20

5 Northern Irish Pilot with Andy Keery

5.1 Sensor technology used:

For the pilot with Andy Keery we chose traditional sensor technology I.e. temperature and humidity monitoring. As documented above, the Andy Keery pilot used the same technology that was developed for Musgrave, i.e. a Digital Matter Eagle logger with a T9602 Temperature / Humidity probe and DS18B20 Temperature probe. For this pilot, since the cold stores are static, trip detection was disabled.

Implementation of the prototype with pilot tests:

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 while stationary so that accurate monitoring could be performed. 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. Figure 18 below shows where the external power was added to the eagle, and an image captured during on-site installation at the Belfast Continental Market.

Figure 18: Left, eagle logger with external power supply cable added; Right, installation at Belfast 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.

5.2 List of the equipment deployed in the pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Digital Matter (South Africa)	Eagle logger	Upload real-time data, Trip detection
Amphenol	T9602 T/RH sensor	To measure temperature and humidity
Maxim Integrated	DS18B20	To measure second temperature (different zone in van)
Pololu	2119 voltage regulator	Boost Eagle supply voltage from 3.3V to 5V to power DS18B20

6 Northern Irish Pilot with WD Meats

6.1 Sensor technology used:

For the pilot with WD 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.

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. The sensor is IP67 protected and has an external probe, highlighted below (figure 19).

Figure 19: Ursalink UC-11 with foam probe for accurate humidity monitoring

Installation

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. 20 shows the gateway location setup.

Figure 20 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.

Sensor installation

For the first iteration of the dry-age trial, the sensors were mounted to the side of the chamber using double-sided Velcro.

Figure 21: Original velcro mounting solution for sensors

However, due to the humidity build-up over the 21-day period of dry-ageing beef, some the Velcro failed, and the sensors fell to the ground. This unfortunately destroyed one sensor beyond repair. Therefore, a more robust mounting solution was required to ensure sensors stayed affixed in the correct position and so repeat damage did not occur. We chose cable ties and hung the sensors from the hooks that the hindquarters go on for the next iterations. The Ursalink UC11 sensors were placed in the 4 corners of the dry age chamber going forward. The sensors were mounted to the hooks which hold the hindquarters using cable ties so that they could be removed after the 21-day ageing period. 2 sensors were located at the front of the chamber closest to the refrigeration unit, and 2 at the rear, closest to the door. Figure 22 shows the sensor location setup.

Figure 22 Sensor installation location inside the dry-age chamber. Sensors are mounted to the hooks which hold the hindquarters using cable ties so that they can be removed after the 21-day ageing period. 2 sensors are located at the front of the chamber, and 2 at the rear.

6.2 List of the equipment deployed in the pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Ursalink	UC11-T1	To measure T° and humidity
Multi-Tech	Multi-Tech Conduit (MTCDT-AEP)	LoraWAN gateway to reach the cloud

7 Irish pilot

7.1 Sensor technology used:

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 previously deployed in Northern Ireland for a similar use case had been discontinued and was not available from our suppliers. For this reason, other LoRaWAN wireless sensors were evaluated. After screening of possible sensor solutions, the Elsys ELT-2 Internal Antenna was chosen given its simplicity in terms of installation and configuration, compact size, waterproof feature, integrated internal sensors including temperature and humidity, as well as the fact that Whysor already had experience working with Elsys sensors. It is worth noting that, even though the ELT-2 had internal sensors available, it was also possible to couple it with external probes for temperature humidity, switch, soil moisture, among others.

Figure 23 Elsys ELT-2 Internal Antenna sensor (Elsys, Sweden).

Battery lifetime
According to manufacturer specifications, the battery life is estimated to be up to 10 years - although results may vary depending on sample interval, transmit interval, data rate, and environmental factors. An ELT-2 Internal Antenna sensor is powered by one 3,6V AA lithium battery.

Six months after the sensors were deployed at Burns Farm Meats, battery voltage readings transmitted by the sensors remained high and are only 0.1 % lower on average since the day of installation.

Sensor location
A total of 10 ELT-2 sensors were deployed in Burns Farm Meats. This company had 2 refrigeration chambers within their premises, this way 6 sensors were placed in the larger of these chambers and 4 in the smaller one. 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 locked into place, these were set at a height utilising the metal structure used to move meat 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 - standard 10 cm long cable ties were used to lock sensors in position. Also, sensors were spatially distributed so that readings would be

recorded from different areas: closer to the door, near the refrigeration units, and in the case of the large chamber, from an area in the middle of these two.

Figure 24 Elsys ELT-2 Internal Antenna sensors deployed in the large chamber at the Burns Farm Meats premises.

Sensor data upload to the cloud – installation of a gateway device

Due to a limitation in the LoraWAN network coverage in Ireland, the IoT system deployed for this pilot test relied on the installation of a gateway device that would ensure a continuous upload of real-time sensor data to the cloud. The gateway chosen for this particular case was the Kona Micro IoT gateway (Tektelic, Canada), which consisted of a compact-sized, LoraWAN-enabled device which could effectively be used to transfer sensor data to the cloud in real-time.

In order to ensure communication between the gateway and the ELT-2 sensors, the Kona Micro IoT gateway was pre-configured to enable connection with the cloud server, and deployed in an office space at Burns Farm Meats physically close to the refrigeration chambers and within reach from the sensors. The gateway was then connected to the internet via an ethernet cable to their router.

Upgrading of the alerting system

In February 2023, an external switch probe was connected to one of the sensors to obtain binary readings on the chamber door status: a Surface Aluminium Contact Normally Closed (Challenger, UK). The reason for this was an attempt to upgrade the alerting system at Burns Farm Meats. 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 led 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 amount time before sending alerts, the REAMIT team decided to add an external switch probe that could provide information on the status of the door.

Figure 25 Image showing the Surface Aluminium Contact Normally Closed (Challenger, UK) switch.

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 close 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 into contact when doors were closed.

7.2 List of the equipment deployed in the pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Elsys (Sweden)	ELT-2 Internal Antenna	1. Measurements of temperature and relative humidity (integrated internal sensors enclosed in an IP67 box) 2. Transmit (Lora) real-time sensor data to a nearby gateway device
Tektelic (Canada)	Kona Micro IoT Gateway	LoraWAN enabled device used to upload real-time data to the cloud (connected via ethernet cable)
Challenger (UK)	AC03 - Surface Aluminium Contact Normally Closed	Contact sensor for the doors of the refrigeration chambers to detect when these are open

8 French Pilot

8.1 Sensor technology used

The sensor that was used at the French pilot is: Raman spectrometer

Description and explanation of the technology

UoN proposes new strategy for the rapid screening of food quality using a spectroscopic technique called Raman spectroscopy. This innovative approach can non-invasively analyze food samples ranging from raw to elaborately processed products, providing a fast and accurate assessment of food quality.

Raman spectroscopy is a powerful analytical technique that utilizes laser light to identify and analyze the chemical composition of materials. This technique is based on the interaction of light with molecular vibrations, which leads to a unique spectral fingerprint that can be used to identify and quantify various components within a sample.

In the context of food quality analysis, Raman spectroscopy can provide valuable information on the chemical composition, structure, and functional properties of food ingredients and products. This includes information on the presence and concentration of nutrients, contaminants, additives, and other chemical components that affect the sensory and nutritional properties of food.

Advantages:

- Non-invasive technique, which allows for the analysis of food samples without destroying or compromising their quality or safety.
- Provides a fast and accurate assessment of food quality and composition, enabling rapid screening of large volumes of food products.
- Enables the identification and quantification of various chemical components within a food sample, including nutrients, contaminants, additives, and other functional ingredients.
- Can be applied to a wide range of food products, from raw to elaborately processed products.
- Does not require extensive sample preparation, making it a cost-effective and time-efficient method.
- Can be used to identify and characterize food ingredients and products, helping to improve product quality, consistency, and traceability.

List of the experiments undertaken before testing in real conditions

Before testing in real conditions, several experiments were undertaken in the laboratory to set up the equipment and determine the technical parameters of analysis for different food matrices. The experiment plan involved analyzing multiple samples, and the monitoring process took several days (e.g., 30 days for chicken samples).

Example of analyzed samples:

- ✓ Ground beef
- ✓ Shrimp samples
- ✓ Chicken meat (from supermarkets)
- ✓ Fruits samples (apples, pear and banana)
- ✓ Egg samples (from IGRECA Company)
- ✓ Chicken meat (from Routhiau company)

Implementation of the prototype with pilot tests

This sensor was developed and updated in the GEPEA lab at the university of Nantes and below are the stages needed to adapt the portable Raman sensor for pilot testing:

1) Installation and assembly of equipment
2) Implementation of the analysis protocol (experimental setup)
3) Setting up the data transmission to servers
4) Data exploration and statistical scripts
5) Validation of the approach at lab scale
6) Automation of the analysis process
7) Validation of the approach in real semi-real conditions in a cold room (preparing the system for field analysis).
8) Search and find interested companies.
9) Integration of the system in a refrigerated food truck
10) Validation of the sensor in the field

For more details on how to install and set up the sensor, as well as how the Raman sensor progressed through each stage of testing until real-time testing, please refer to Deliverable 3.2 (User Manual) and Deliverable 3.3 (Pilot Storytelling).

Difficulties encountered during sensors installations and the adaptations

Stages needed to adapt the Raman sensor for pilot testing	**difficulties encountered**
1) Installation and assembly of equipment	The shipment was impacted due to the covid pandemic (one year of delay)
2) Implementation of the analysis protocol (experimental setup)	No difficulties for this step (time-consuming step)
3) Setting up the data transmission to servers	Problems of connectivity with BED server. Problems of connections between computers of different institutions.
4) Data exploration and statistical scripts	The need to develop scripts and data processing models (time-consuming step)
5) Validation of the approach at lab scale	No difficulties for this step
6) Automation of the analysis process	More work should be done regarding the automatic adjusting of the focal length or the distance between the laser and the sample (Z)

7) Validation of the approach in semi-real conditions, i.e. in a cold room (preparing the system for field analysis)	Laser source didn't work at temperatures less than 10 ºC.
8) Search and find interested companies	Covid pandemic: companies had many problems and were not able to give us time to test the system
9) Integration of the system in a refrigerated food truck	The Raman portable system needs to be integrated into the truck, with the use of an inverter to convert the power from the truck's battery to power the sensor. Speed bumps along the road can affect the sensitivity of the Raman signal.
10) Validation of the sensor on field	Finding companies to test the Raman sensor in their transportation trucks

8.2 List of the equipment deployed in the pilot

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Ocean optics	Sensor Name: Raman spectroscopy (PROC19069MSF) **Technical characteristics** ✓ Wavelength range: 785 nm **Configurations** ✓ support the range of 185–1100 nm ✓ Interchangeable slits: Multiple widths from 5 µm-200 µm; SMA/FC bulkhead with no slit also an option ✓ Optical resolution: 0.14-7.7 nm ✓ System SNR: 1000:1 ✓ A/D resolution: 18 bit ✓ Dynamic range: 85,000 (typical) ✓ Stray light: <0.08% at 600 nm; 0.4% at 435 nm ✓ Buffering: 15,000 spectra ✓ TEC: Cooling to -40 ºC below ambient-40 ºC to +50 ºC temperature limits	To measure the chemical composition
InPhotonics	Fiber-optic probe (, RPB78)	To acquire raman spectra

Standa	3-axis motorized platform (8-0026) 3-axis controller (8SMC4-USB-B8-B9)	To move the sample in different directions (X, Y, Z)
QUIPO Locker	A lockable box (dimensions: height 450 mm x width 450 mm x depth 450 mm) covered on the inside with black opaque adhesive film (Adhesive vinyl, ME310-61). The box is equipped with four adjustable legs.	Holds all the Raman parts mentioned above Protect the fiber optic probe from light
	Pilot computer that contains the following programs: • An API to automatically control the spectrometer and the 3-axis motorized platform allowing multiple sample measurements: Raman Automatization (IUT de Nantes) • Laser operating software (Oxxius, LaserBoxx HPE series) • Spectrometer operating software: OceanView (Ocean Optics) • 3-axis motorized platform operating software: XILab (Standa).	Holds the software required to automate the process from moving the sample to acquiring spectra and saving them in the spc format.

9 UK pilot test with Human Milk Foundation

9.1 Sensor technology used

For this pilot test we chose traditional sensor technology.

Sensors in the first round of testing

The challenge at Human Milk Foundation is how to monitor in real time temperature of donor human milk during transportation in milk bags en route donor's house – human milk bank – hospital/home of a vulnerable baby. The REAMIT technical partners proposed a sensor which seemed most suitable to address this challenge: Digital Matter Falcon Logger—GPS/Accel, DS18B20 T (Figure 1). Whysor partners assembled this sensor by themselves.

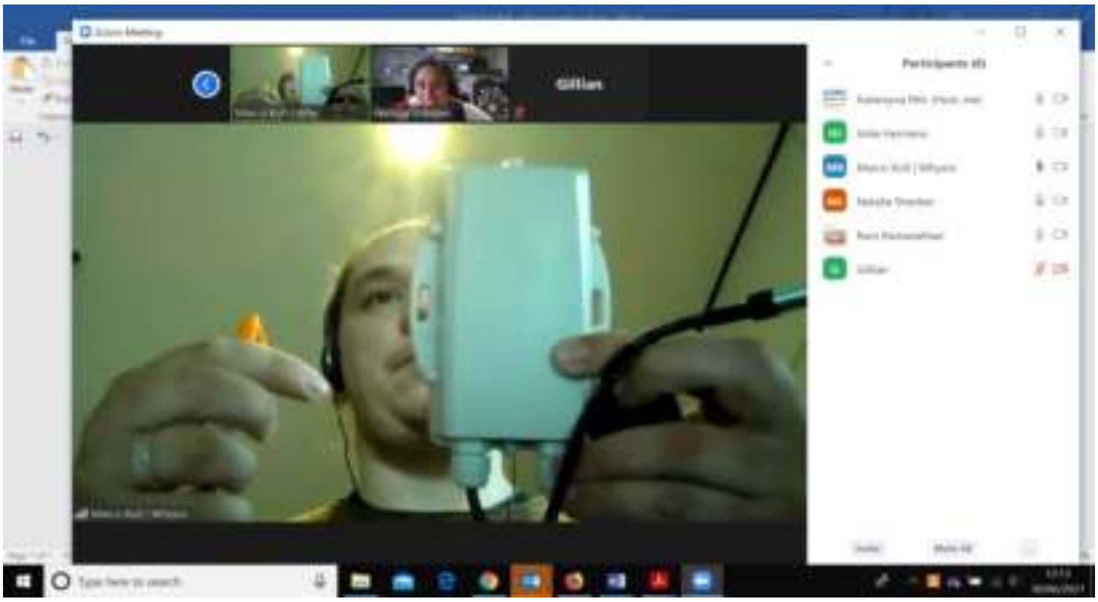


Figure 1. Digital Matter Falcon Logger—GPS/Accel, DS18B20.

The sensor is battery driven, has a GPS locator inside, sends data every 2 min when a vehicle (car/bike) is driving (when a vehicle is still, data can be sent at lower frequency).

In June 2021, partners at Whysor, tested both sensors by driving them for one week in a private car in order to check the internet connectivity in the different regions of the Netherlands and see how the sensors functioned when the quality of internet connectivity fluctuated. The aim of this test was to simulate real life circumstances which could occur when transporting human milk bags across different regions in the UK with varied quality of connectivity.

In September 2021, partners from Whysor installed two sensors in two insulated bags transporting donor human milk at Human Milk Foundation in the UK (Figure 2). Both sensors use NBIOT (band system in the UK, special kind of mobile connection for low power devises). Whysor noted that it was likely that NBIOT was weak in some parts of UK, while it was stronger in other parts of UK.

Figure 2. Insulated bag used by the Human Milk Foundation to transport donor human milk.

Both sensors were connected to Whysor cloud and dashboard and started to record data on temperature inside human milk bags when they were en route transporting donor human milk. Unfortunately, partners at Whysor observed that sensors connected to internet sporadically (e.g. once a week). Partners at Whysor confirmed that sensors needed to be reconfigured. Reconfiguration has been executed remotely, but for this to happen the sensors needed to be connected to internet. They needed to be online for relatively short time to update the configuration. Partners at HMF confirmed that there were connectivity issues in the premises of HMF and they agreed that the sensors would be sent on a trip where internet connection was strong. In this way, partners at Whysor executed remote reconfiguration. Both sensors were sent on trips with human milk bags, but still one of them still did not connect to network and hence, it did not update its configuration. To address this challenge, partners at Whysor visited HMF in September 2021 and reconfigured both sensors. They also created a dashboard for HMF and made sure sensors started to record data in the dashboard.

Partner from Whysor fixing sensor connectivity issues at HMF.

Partner from Whysor creating the dashboard for HMF.

In October 2021, both sensors (1574 and 8516) reported temperatures below 10°C, which was recorded in the REAMIT dashboard for Human Milk Foundation (Figure 3 and Figure 4). The dashboard provided information about the date and time of measurements.

Figure 3. Temperature data collected by sensor 1574 and recorded in the REAMIT dashboard for Human Milk Foundation.

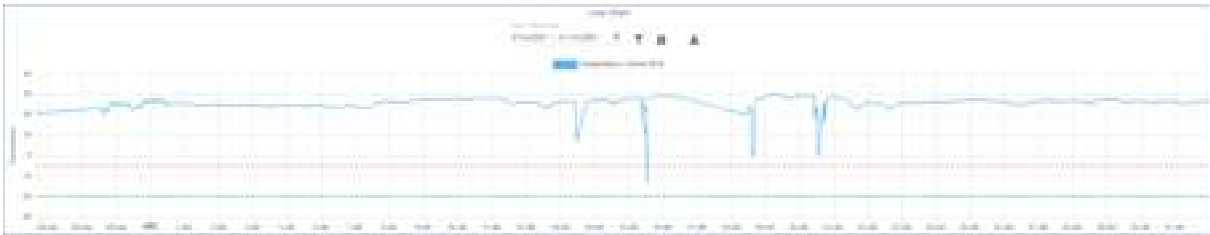


Figure 4. Temperature data collected by sensor 8516 and recorded in the REAMIT dashboard for Human Milk Foundation.

Figure 5. Temperature data collected by sensors 1574 and 8516 and recorded in the REAMIT dashboard for Human Milk Foundation.

Sensors in the second round of testing

An important challenge was how to avoid false alerts in situations such as for example when a bag with donor milk is opened. To address this challenge a binary sensor was proposed.

Following the request from HMF to scale up the pilot test, in February 2022, the University of Bedfordshire purchased from a South African supplier (due to shortage of sensor equipment from European suppliers) 10 new loggers (the larger Digital Matter Eagle, due to supply issues with the smaller Falcon) and from a UK supplier 10 temperature and humidity sensors (Amphenol T9602 T/RH) and 10 binary sensors. They were wired at BED by REAMIT partners from BED and Ulster in March 2022. BED purchased 40 batteries (4 per logger) and Velcro for assembling the 10 sets of sensors.

Once assembled and connected to internet, all the 10 loggers and sensors became immediately visible in the Whysor dashboard for Human Milk Foundation.

The 10 new Eagle loggers, 10 new temperature sensors and 10 binary sensors for HMF were installed at HMF by the REAMIT team in May 2022. The loggers were initially reporting data every 5 minutes. REAMIT partners decided to change the trip configuration to preserve the sensor battery life (hence the readings stopping at 11:45 on the charts). Consequently, the loggers started to take measurements every hour and uploaded data to the cloud every 12 hours when there was no motion detected. The loggers logged data and uploaded it every 5 minutes when motion was detected (that is, when the bag was in a trip) to allow for real time monitoring and alerting.

9.2 List of the equipment deployed in the pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Digital Matter (South Africa)	Eagle logger	Upload real-time data, Trip detection
Digital Matter (South Africa)	Falcon logger	Upload real-time data, Trip detection
Amphenol (USA)	T9602 T/RH sensor	Measurements of Temperature and Relative Humidity
RS (UK supplier)	Binary sensor	To monitor the status of the milk bag (open or closed).

Cost of equipment:

1 binary sensor: GBP 7.36

,3V,I2C O/P: GBP 50.59

Logger EAGLE-4G: USD 156

10 UK pilot test with Yumchop Foods

10.1 Sensor technology used

The challenge at Yumchop Foods is to monitor in real time temperature and humidity in 10 different zones inside Yumchop Foods factory. To address this challenge, the REAMIT team has proposed traditional temperature and humidity sensors which help Yumchop Foods company owners:

- ensure that frozen food is stored in the right temperature inside the food factory;
- provide food fingerprint (i.e. data on the conditions in which food produced by Yumchop Foods has been stored and transported);
- ensure that frozen food is stored in the right temperature in Yumchop Food's vending machine at Victoria Coach Station in London, UK.

<u>Sensors installed inside Yumchop Foods factory:</u>

Technical partners at Whysor assessed the company's needs and proposed:

- 10 ELT Lite logger (from ELSYS in Sweden)
- 10 Digital temperature sensors (from ELSYS in Sweden)

In sprint 2021, BED purchased this equipment, which was delivered in mid-June 2021 to Whysor's office in the NL for configuration. Once configuration has been completed, partners from Whysor installed 10 sensors and a gateway at Yumchop Foods factory during the visit on 28 September 2021. Sensors were installed in the following zones (Figure 1):

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)

Figure 1. Yumchop's factory zonal layout

During the visit on 28 September 2021, the following thresholds for all the sensors installed at Yumchop Foods were established following the input from the company's owners:

Cold store (fridges):

Temperatures need to be < + 5 °C.

Alerts will be sent when 2 measurements in a row are over + 5 °C.

Cold store (freezers):

Temperatures need to be between -24 °C and – 18°C.

Alerts will be sent when 2 measurements in a row are over – 18 °C

Partners at Whysor created a dashboard for Yumchop Foods. The company's key staff (Michael, Abi and Francis) would receive log-in data to access and use the dashboard (Figure 2), which shows real time temperature in all 10 zones at the factory where REAMIT sensors have been installed.

Figure 2. Dashboard for Yumchop Foods.

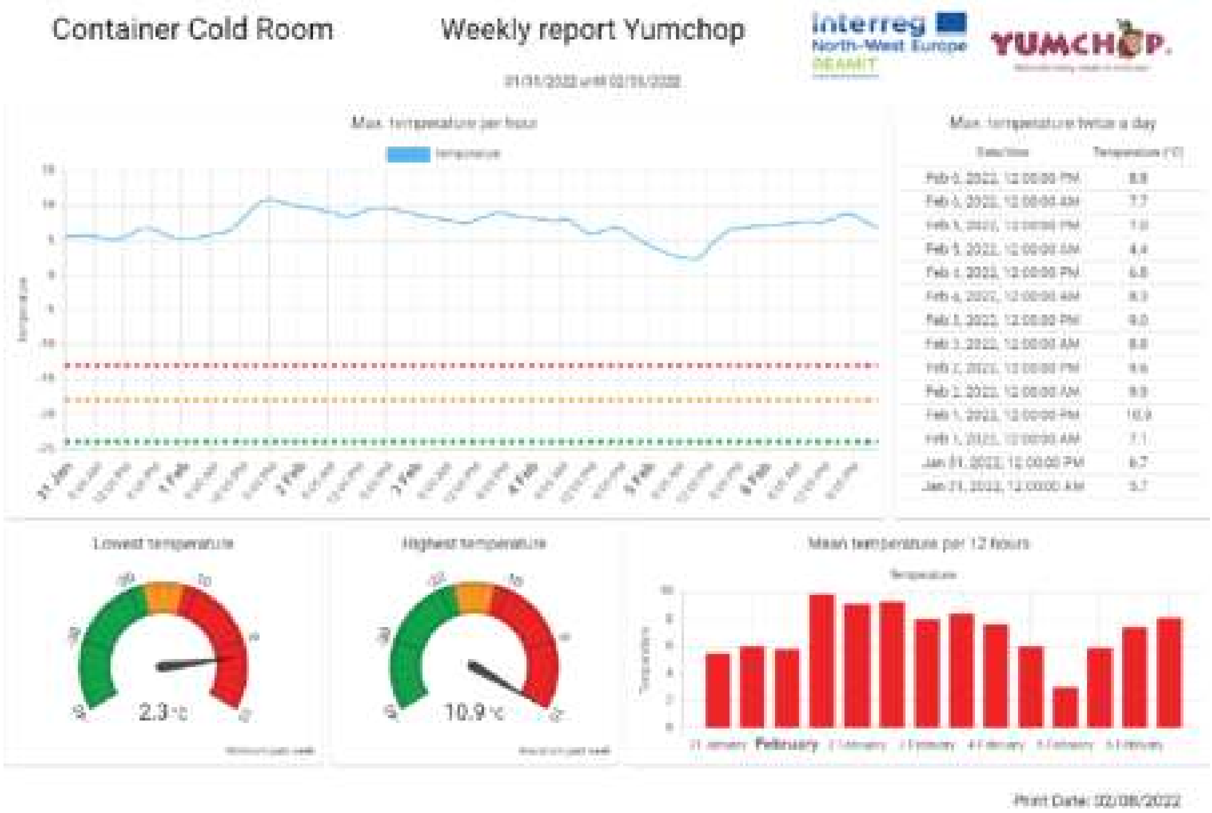


Figure 4. Weekly report from dashboard from one of the zones at Yumchop Foods.

<u>Sensor installed at Yumchop Foods vending machine</u>

With full temperature monitoring and alerting in place throughout Yumchop's factory, the company wanted to extend the use of REAMIT technology further down the supply chain. Yumchop also owns vending machines located at various convenient locations, including one at the busy London Victoria Coach station, which sees around 14 million passengers every year. Since this vending machine is located far from their production facility, it is difficult for Yumchop's staff to monitor if the machine is functioning correctly. To address this, Yumchop wanted to deploy the same remote temperature monitoring technology used at their factory to instantly alert staff of any refrigeration issues in the vending machine. Having a complete overview of their storage temperatures from one centralised dashboard location was also important for Yumchop.

On 24 March 2023, REAMIT partners from Ulster University UK and University College Dublin, Ireland, visited the Yumchop Foods vending machine at the Victoria Coach Station in London for the installation of REAMIT technology sensors.

As the vending machine was situated in the UK, there was no LoRaWAN network connection. Moreover, as the installation was a standalone sensor, it did not make financial sense to install a LoRa gateway, meaning a new sensor for Yumchop had to be chosen. As a substitute, the Digital Matter Eagle, which is cellular-based, and it has been previously tested at Musgrave, Biogros, and Human Milk Foundation, was selected. On 24 March 2023, REAMIT staff went to the vending machine located in London Victoria coach station and installed the Eagle logger.

REAMIT team installed sensors at Victoria Coach Station in London, for Yumchop Foods, UK.

Unfortunately, the REAMIT team has found that there has been LTE-M connectivity issues at the coach station which means the sensor cannot upload data to the cloud. The REAMIT team are in contact with the internet service provider to try to establish a solution to the problem, which is thought to be an infrastructure issue. If the issue persists, it may be feasible to deploy the sensor at another Yumchop Foods location, such as Yumchop branded freezer situated at the University of Essex.

10.2 List of the equipment deployed in the pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
ELSYS, Sweden	ELT Lite logger	Upload real-time data.
ELSYS, Sweden	Digital temperature sensors	To measure temperature.
MultiTech	Multi-Tech Conduit (MTCDT-AEP)	LoraWAN gateway to reach the cloud

11 Northern Ireland lab testing of FreshDetect

11.1 Sensor technology used

The FreshDetect BFD-100 is a handheld device based on non-invasive fluorescence spectrometry. It operates at an emission wavelength of 405nm, emitting less than 10 mW of optical radiation per light source at this specific wavelength. The device captures the emitted fluorescent light using a spectrometer, which are then processed to provide indications of surface microorganisms present on the food item as well as the characteristics of the food matrix itself, such as porphyrin fluorescence with distinct wavelengths in the "green-red" range. Preloaded onto the device are special algorithms which analyse the fluorescence signals and can estimate the total viable count (TVC) of meat products, which refers to the number of viable microorganisms present in each sample. By analysing the intensities and wavelengths of the fluorescence signals, the FreshDetect device can determine the TVC per square centimetre (TVC/cm^2) of the meat sample. Figure 26 illustrates the FreshDetect being used to assess the quality of meat.

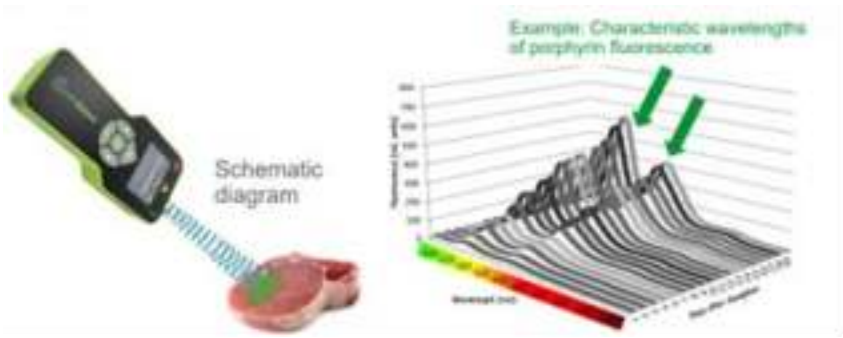


Figure 26: Schematic diagram of FreshDetect and Characteristic fluorescence spectra

However, within the scope of the REAMIT project, researchers have explored the potential of using the FreshDetect device to assess the freshness of other household food items that are prone to spoilage. This investigation aims to determine if the device's fluorescence-based approach can provide reliable indications of freshness or spoilage in these different food items beyond its original intended application for meat products through the analysis of the raw captured spectra rather than relying on the premade TVC algorithms.

Figure 27 illustrates the measuring principle of the FreshDetect device. The device incorporates a 405nm laser that is integrated into the handheld unit. This laser is responsible for exciting the sample being analysed. In conjunction with the laser, the device also features a 460-900nm spectrometer, which is also housed within the handheld unit. During the measurement process, the 405nm laser emits light onto the sample, causing it to fluoresce. The fluorescence emitted by the sample contains valuable information about its properties and is captured by the spectrometer within the FreshDetect device. The raw spectra signal is stored on the device and can be analysed offline on a computer. Through the use of sophisticated algorithms and analysis techniques, data produced from the FreshDetect can be combined with known information about the food matrix to estimate properties such as freshness, quality, or other relevant characteristics of the sample. In turn, it is hoped that this will allow researchers to produce new models of food quality estimation which could be loaded onto the device and used by consumers in the agri-food supply chain going forward.

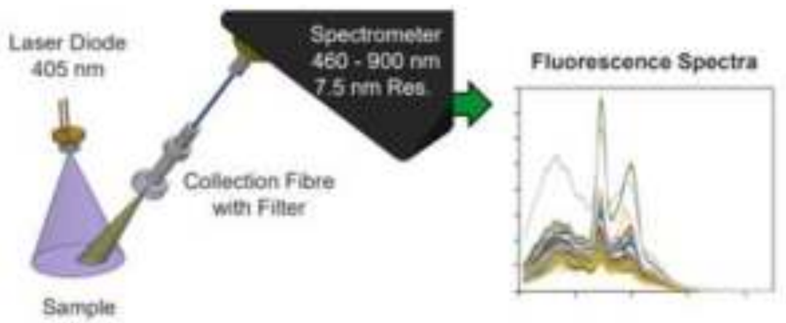


Figure 27: Measuring principle of the FreshDetect device. A 405nm laser built into the handheld device excites a sample, and a 460-900nm spectrometer also housed within the handheld unit measures the emitted spectra. The fluorescence spectra can then be analysed.

Advantages of the FreshDetect:

- Non-invasive technique, which allows for the analysis of food samples without destroying or compromising their quality or safety.
- Much simpler, cost-effective and faster than typical Petri dish and laboratory tests which can be tedious.
- Handheld, battery operated device allows for the measurement and analysis of spectra in a real-working environment rather than being limited to laboratory locations, significantly improving the opportunities for spectroscopy to be a valid contender in food quality analysis throughout the supply chain.
- Provides a fast and accurate assessment of food quality and composition, enabling rapid screening of large volumes of food products.
- Can be applied to a wide range of food products, from raw to elaborately processed products.
- Does not require extensive sample preparation, making it a cost-effective and time-efficient method.

List of the experiments undertaken before testing in real conditions

One of the proposed extensions to the FreshDetect's functionality was to produce a model for the detection of milk freshness. Before testing in real conditions, however, several experiments were undertaken in the laboratory to build a model for the detection of milk spoilage. To achieve this, a robust sampling protocol was defined in order to ensure consistent measurements were acquired and to reduce the likelihood of errors being introduced during the data collection required for model production.

To ensure that the FreshDetect took samples from the same distance and under the same lighting conditions during each scan, a custom 3D printed case was designed which held the sampling container (a glass beaker) inside. The case consisted of a lid which contained the cutout for the FreshDetect's laser and spectrometer, and a base which held the beaker. Once the lid was placed on the base, the FreshDetect would be positioned at the required distance from the top of the liquid for data collection. Presented in Figure 28 is a depiction of the experimental setup.

Figure 28: Milk sampling procedure using custom designed and printed 3D housing to ensure the same light level and distance was used between recordings.

The FreshDetect was designed to take measurement upon button push. However, to collect enough data to build a useable model, an automated way of recording scans was required. Using the *Expert Software Tool* provided by FreshDetect, it was possible to enable automatic scans on the FreshDetect with a user-defined time period between scans. By enabling this mode, it was possible to press the begin scan button once to start the experiment and once again to finish the experiment. This allowed the researchers to collect a large dataset of spectra samples over a 48-hour period (scans every 15 minutes) without needing to tediously press the button each time. An added benefit was that the experiment could be run unsupervised.

11.2 List of the equipment deployed in the pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
FreshDetect, Germany	BFD-100	Handheld spectrometer used to excite food sample and measure spectra

12 Contact

Website: www.reamit.eu

#reamit4nwe

www.facebook.com/reamit4nwe

https://www.linkedin.com/company/reamit/

13 Posters on prominent working prototypes

The following pages provide a description of some REAMIT prototypes. These posters have been used to popularize the achievements of the project in various conferences and meetings.

www.reamit.eu

RESOURCE & MATERIALS EFFICIENCY

REAMIT will adapt and apply existing innovative technology to reduce food waste in agribusiness supply chains of North-West Europe

Yumchop Foods and the REAMIT Project

Pilot-test start date: September-2021

YUMCHOP® Naturally tasty meals in minutes!

We are REAMIT

REAMIT is a transnational European territorial cooperation project funded by Interreg North-West Europe (NWE) Programme aiming to reduce food waste. The project focuses on fruits, vegetables, meat and fish supply chains as these are wasted in large quantities. It is being carried out in Ireland, Germany, France, UK and the Netherlands due to the amount of interconnected food supply chains and huge food waste in these countries. The REAMIT project is using existing Internet of Things and Big Data technologies to best fit the needs of the food supply chain management system in the NWE region. Through testing and adaptation, these technologies are being enabled to continuously monitor and record food quality and signal potential food quality issues. Through analytics, owners of 'food at risk of becoming waste' are provided with decision support options to minimise food waste including redistribution to nearby customers. As part of the technology demonstrations, the REAMIT project team is working with Yumchop, helping to reduce food waste.

Who are Yumchop?

Yumchop specialises in producing African flavoured frozen ready meals. They provide flavoursome and authentic food from around the world with an African twist that is frozen to retain its goodness and freshness and minimise waste. Yumchop is using locally sourced raw materials to prepare their ready-meal products. Most of the ingredients are supplied by local vendors, located locally from the production plant of Yumchop in Towcester, Northamptonshire, UK. Their tasty meals are distributed at institutions such as universities or hospitals through self-service automated vending machines. These unattended retailing kiosks have been fitted with an integrated microwave oven which enables them to warm the food upon purchase. However, Yumchop also delivers food to customers' homes through direct purchase at their website, enabling one-off purchases and monthly subscriptions that customers can customise to receive food at their preferred intervals. Moreover, they also supply directly to retailers and large organisations. Click here to view their website.

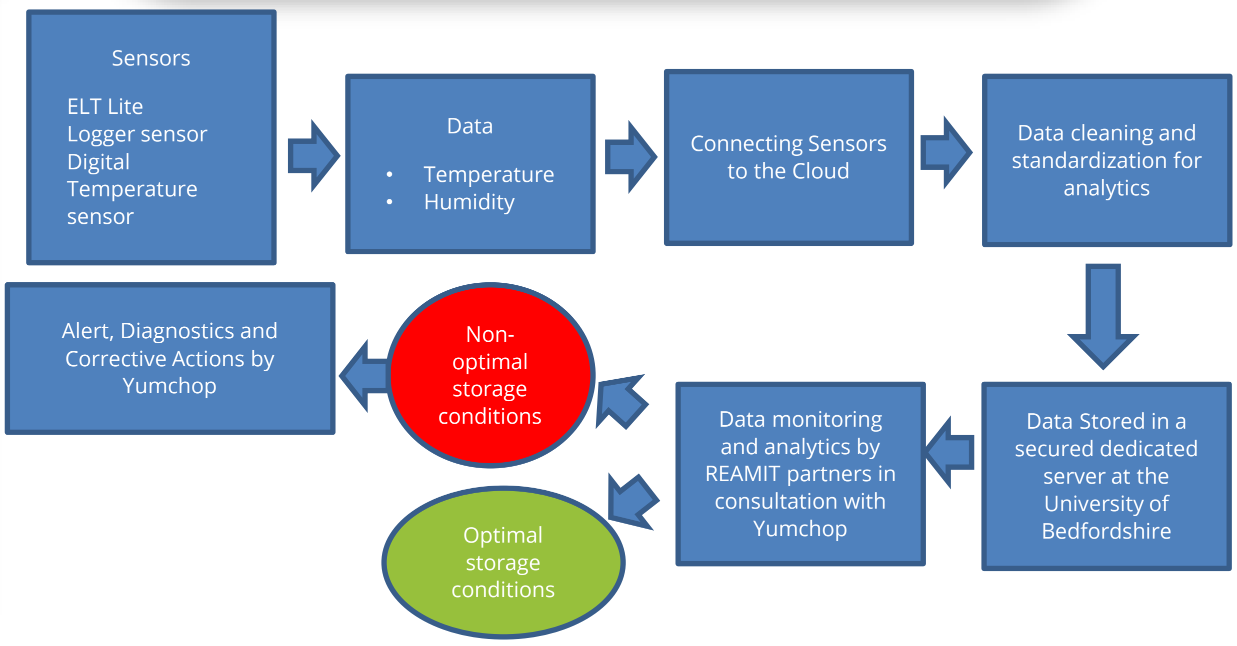
REAMIT-Yumchop collaboration with the University of Bedfordshire

REAMIT Lead partner, the University of Bedfordshire, UK is leading on a technology demonstration pilot test with Yumchop Foods. The REAMIT technology is integrated into the Yumchop operations starting from storing the raw materials and prepared foods in the internal storage until the 'ready-to-eat' meal packages are stored in the vending machines/outlets. In each stage of the operations namely sourcing, preparing, storing, logistics and delivering to customers, the REAMIT sensors monitor the temperature and transmit data to Yumchop team with an alerting system that helps the team know when there is a problem during storage, to avoid the food going to waste. Using REAMIT technology, the company prevents nearly 10% of food from being waste.

This REAMIT Pilot test with Yumchop aims to:

- **Ensure that frozen food and raw materials for preparing the food are stored in the right temperature in the frozen food manufacturer's factory.**
- **Ensure that frozen food is transported at the right temperature from frozen food manufacturer's food factory to where vending machines are located or to private homes (frozen food manufacturer's home delivery service).**
- **Provide food fingerprint (i.e. data on the condition in which food produced by the frozen food manufacturer has been stored and transported).**
- **Adhere to legal requirements (e.g., HACCP) on food quality.**

Current Potential Areas for food Waste	**Scenario 1: Warehouse, Freezers and refrigerators** Sudden and undetected rise in the warehouse temperature overnight. temperature fluctuations, equipment malfunctioning. **Scenario 2: Vending machines** Temperature fluctuations, equipment malfunctioning, user interference.
REAMIT's Solution	**IoT sensors installed and connected to the cloud providing information in real-time means:** • Improved system efficiency by continuously monitoring the temperature of freezers. and refrigerators through an automated process. • Reduced food waste, saving the company from any loss due to temperature fluctuations. • Increase in food quality, revenue and transparency.



REAMIT will adapt and apply existing innovative technology to reduce food waste in the supply chains of North West Europe

www.reamit.eu

The Human Milk Foundation and the REAMIT Project

Pilot-test start date: September-2021

www.humanmilkfoundation.org

RESOURCE & MATERIALS EFFICIENCY

We are REAMIT

REAMIT is a transnational territorial cooperation project funded by Interreg North-West Europe (NWE) Programme. The main aim of the project is to help reduce food waste. The project focuses on fruits, vegetables, meat and fish supply chains as these are wasted in large quantities. It is carried out in Ireland, Germany, France, UK and the Netherlands due to the amount of interconnected food supply chains and huge food waste in these countries. The REAMIT project is using existing Internet of Things and Big Data technologies to best fit the needs of the food supply chain management system in the NWE region. Through testing and adaptation, these technologies are being enabled to continuously monitor and record food quality and signal potential food quality issues. Through analytics, owners of 'food to be at risk of becoming waste' are provided with decision support options to minimise food waste including redistribution to nearby customers. As part of the technology demonstrations, the REAMIT project team is working with The Human Milk Foundation (HMF), helping to optimise the quality of donor human milk and maintain cold chain logistics.

Who are the Human Milk Foundation (HMF)?

The HMF is a UK charity (est. 2018) working to create an equitable national service that can support all families facing feeding challenges. The HMF operates the Hearts Milk Bank, which provides 1000s litres of screened donor human milk (DHM) to vulnerable babies in over 50 neonatal intensive care units, as well as where a bridge to a full milk supply is needed or the mother is receiving cancer treatment. REAMIT will improve logistics and produce first-in-world data on donor milk transportation.

REAMIT-HMF collaboration with the University of Bedfordshire (UoB)

REAMIT Lead partner, the University of Bedfordshire, UK is leading on a technology demonstration pilot test with the HMF

The aim of the REAMIT pilot test with the HMF is to develop a system that monitors the temperature at which human milk is transported from a milk donor to human milk bank and then to the hospital or home where a baby that needs the milk is located. The system will generate alerts if these conditions change to save precious human milk from being wasted and to ensure temperature stability.

This REAMIT Pilot test with HMF aims to -

- Monitor temperatures in individual transport boxes when milk is transported between a donor to the Hearts Milk Bank and from the milk bank to hospitals, hubs or recipient homes.
- To send alerts if these conditions change.
- Maintain transportation temperatures at less than -18°C, according to the national NICE guideline for Human Milk Bank Operations
- Reducing the milk transportation costs by optimizing logistics operations.
- Achieve capacity to support 500 journeys per month

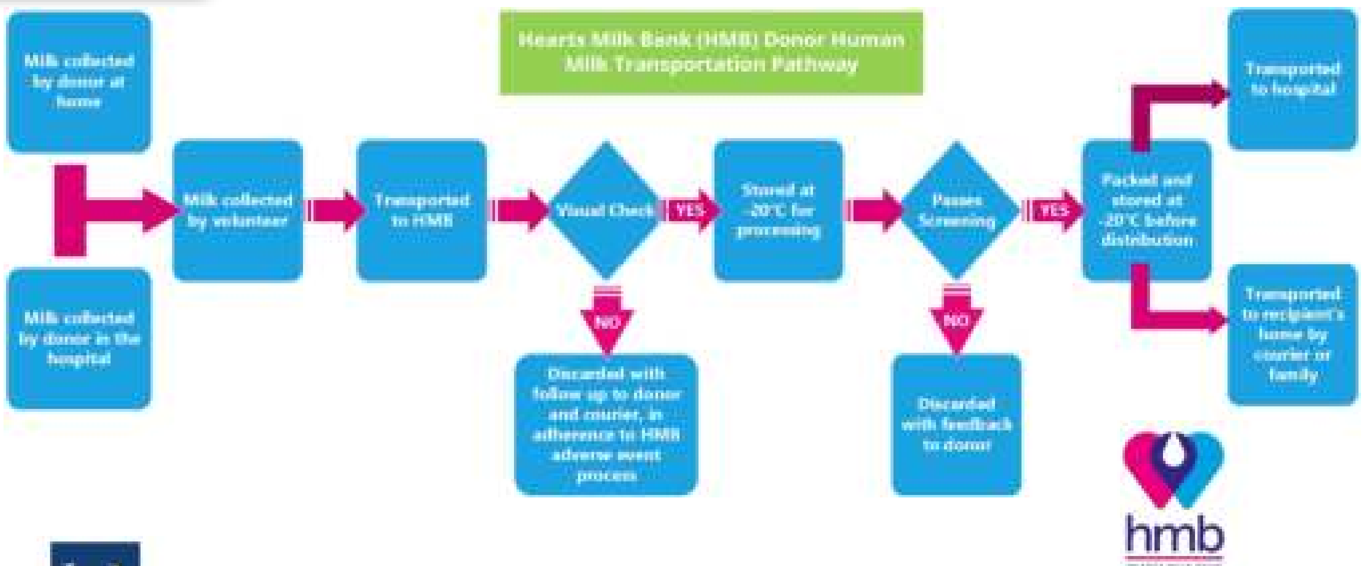
Challenges of DHM storage and transportation

- The main factor related to human milk wastage are **microbiological contamination,** which means around 10% of donated milk must be discarded currently. Fluctuating or high temperature and humidity levels can impact quality**.**
- The HMF is keen to accurately **monitor the temperature** during the transportation as they want to ensure that the milk has remained in optimal conditions from the point of expression until fed to a vulnerable infant.
- Unexpected problem with the freezers delay or skip alerts when the temperature raises. This could result in discarding more than 1000 L of human milk.

REAMIT's Solution

a) Monitoring services and
b) Optimizing the quality control services of human milk banks during transportation, processing and storage.

The REAMIT and HMF teams come together at the Hearts Milk Bank, Hertfordshire, UK



Evaluation of the impact of bad storage (temperature) on the chicken meat quality by Raman Spectroscopy

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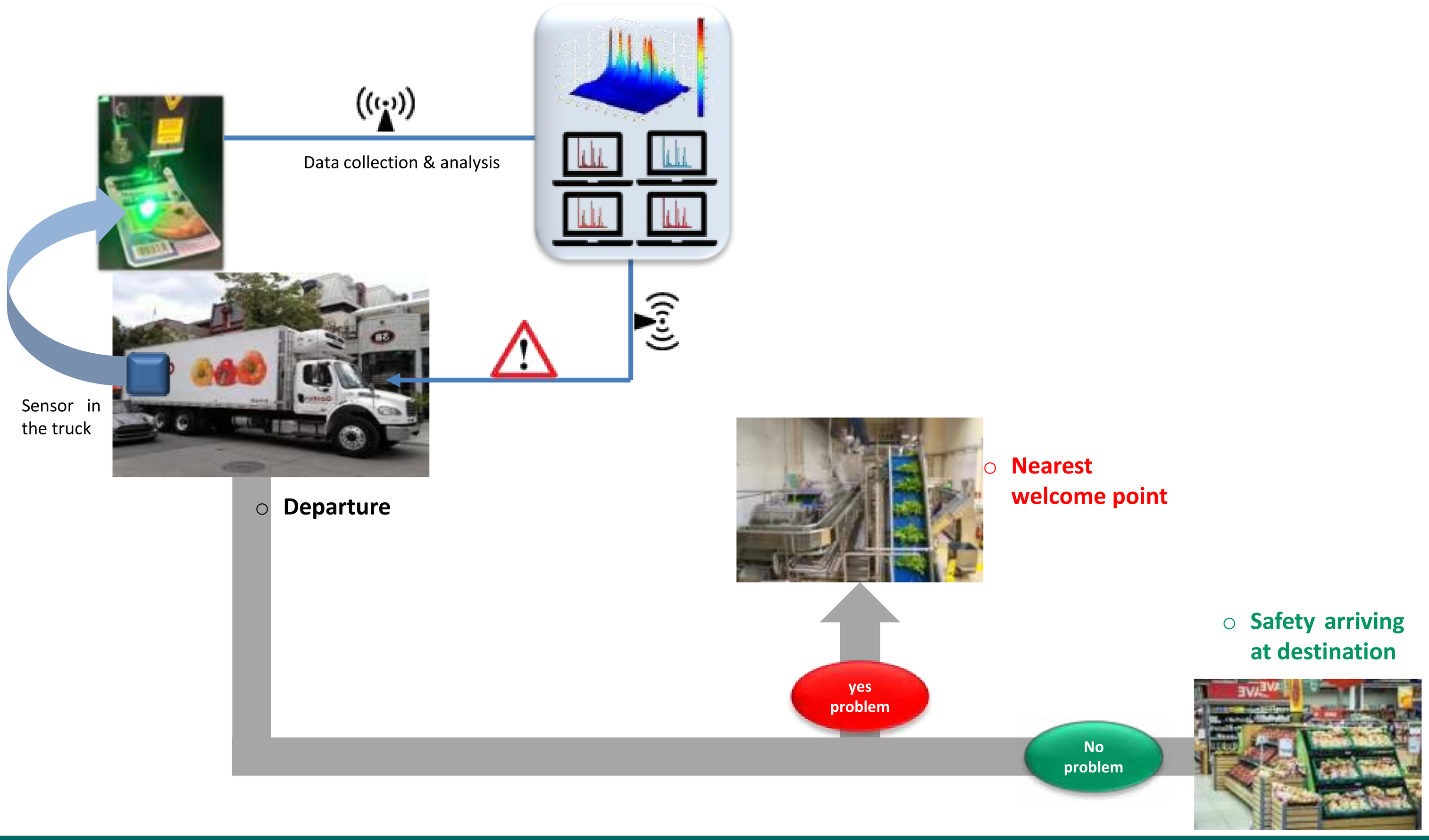
REAMIT project

The REAMIT project proposes to adapt and apply existing innovative technology to food supply chains in NWE to reduce food waste and hence improve resource efficiency. REAMIT will adapt existing technologies to continuously monitor and record food quality and signal potential food quality issues. In this context, optical sensors as Raman spectroscopy will be used for the monitoring of food quality during their refrigerated transport. Through these analytics, owners of "food to be at risk of becoming waste" will be provided with decision support options to minimise food waste including redistribution to nearby customers.



Technical development of Raman spectroscopy pilot

Proof of principle

The first analyses were done in lab-conditions on chicken samples bought from the market. Two conditions were tested: 1) bad storage at 20°C and 2) Good storage at 4°C.

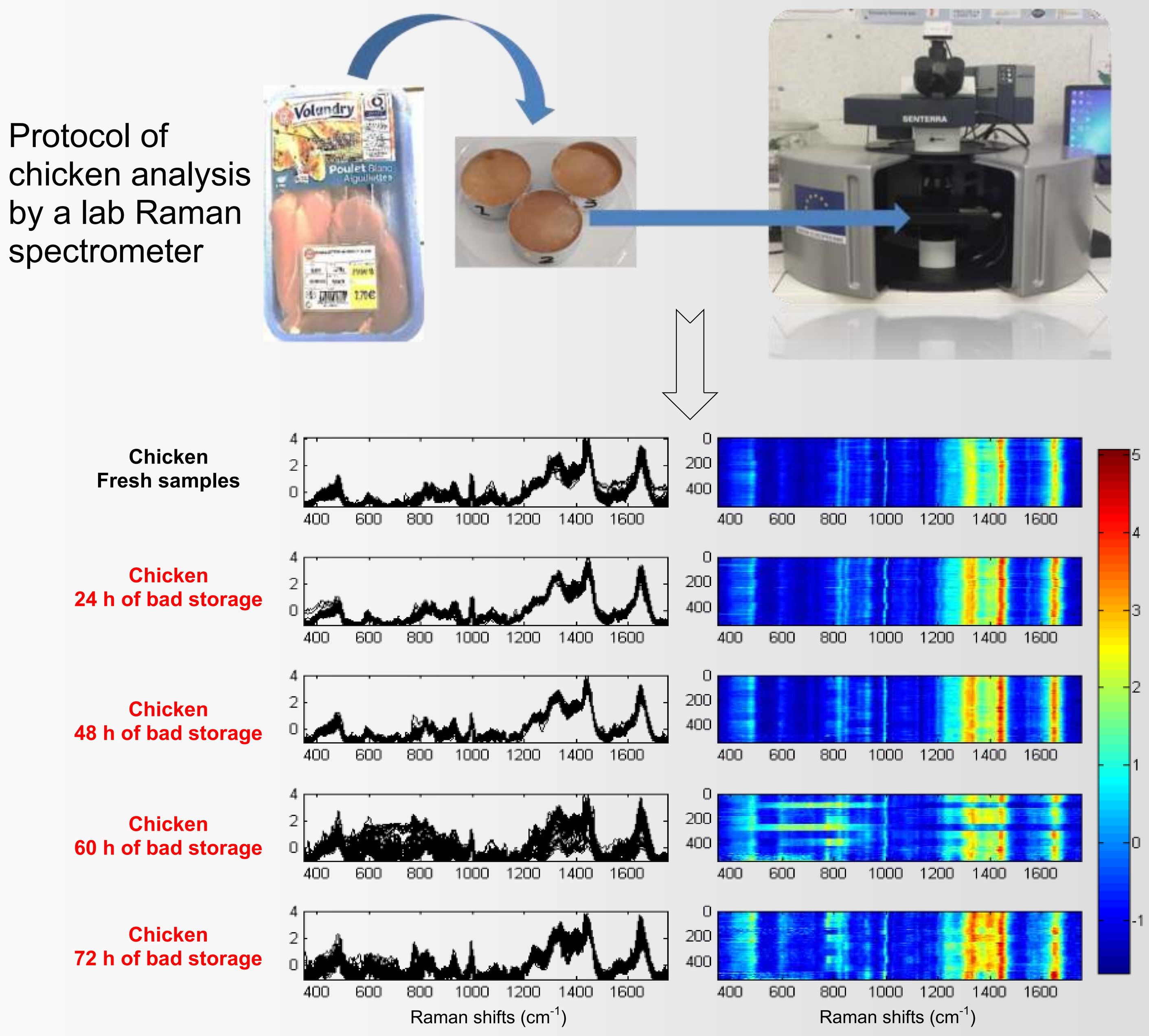
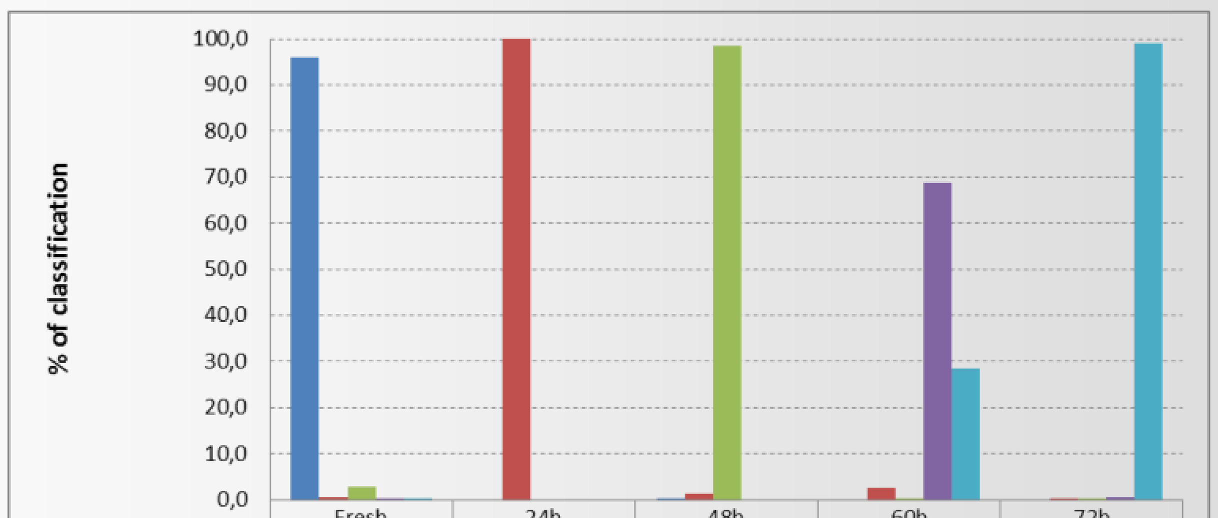


Fig.1: Spectra and 2D plots showing the differences in Raman shifts (in cm^{-1}) and the intensities between the studied samples. Raman parameters were λ= 785 nm, power= 25 mw (on sample) and acquisition time= 30 seconds

The statistical analysis shows the ability of Raman spectroscopy to classify Raman spectra of samples according to their storage temperature.

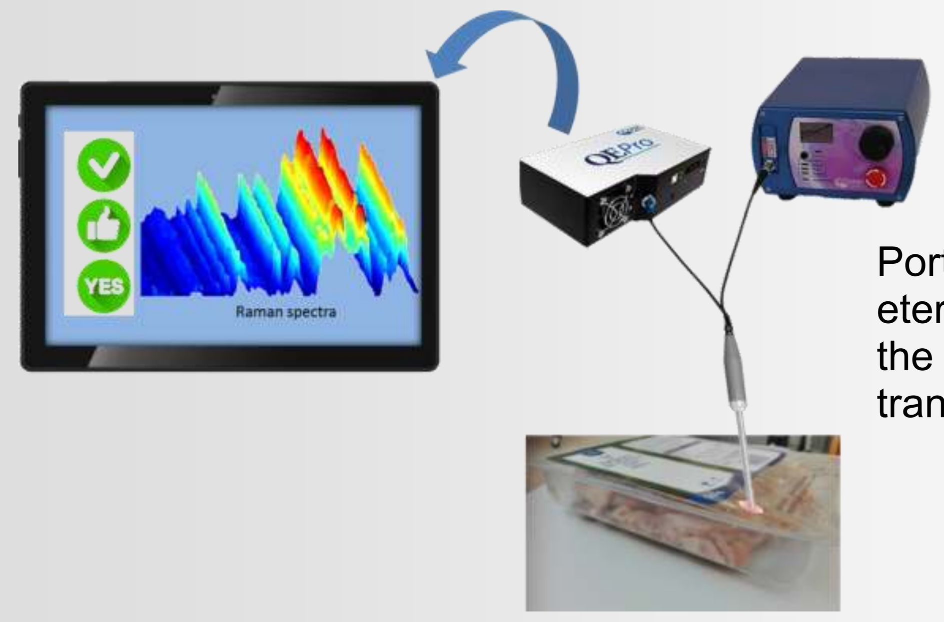


	Fresh	24h	48h	60h	72h
Fresh samples	96,1	0,0	0,1	0,0	0,0
24h of bad storage	0,5	100,0	1,3	2,6	0,3
48h of bad storage	2,9	0,0	98,6	0,1	0,1
72h of bad storage	0,1	0,0	0,0	68,8	0,5
96h of bad storage	0,4	0,0	0,0	28,6	99,1

Fig.2: Classification of the Raman spectra done on chicken samples according to their storage conditions by the factorial discriminant analysis

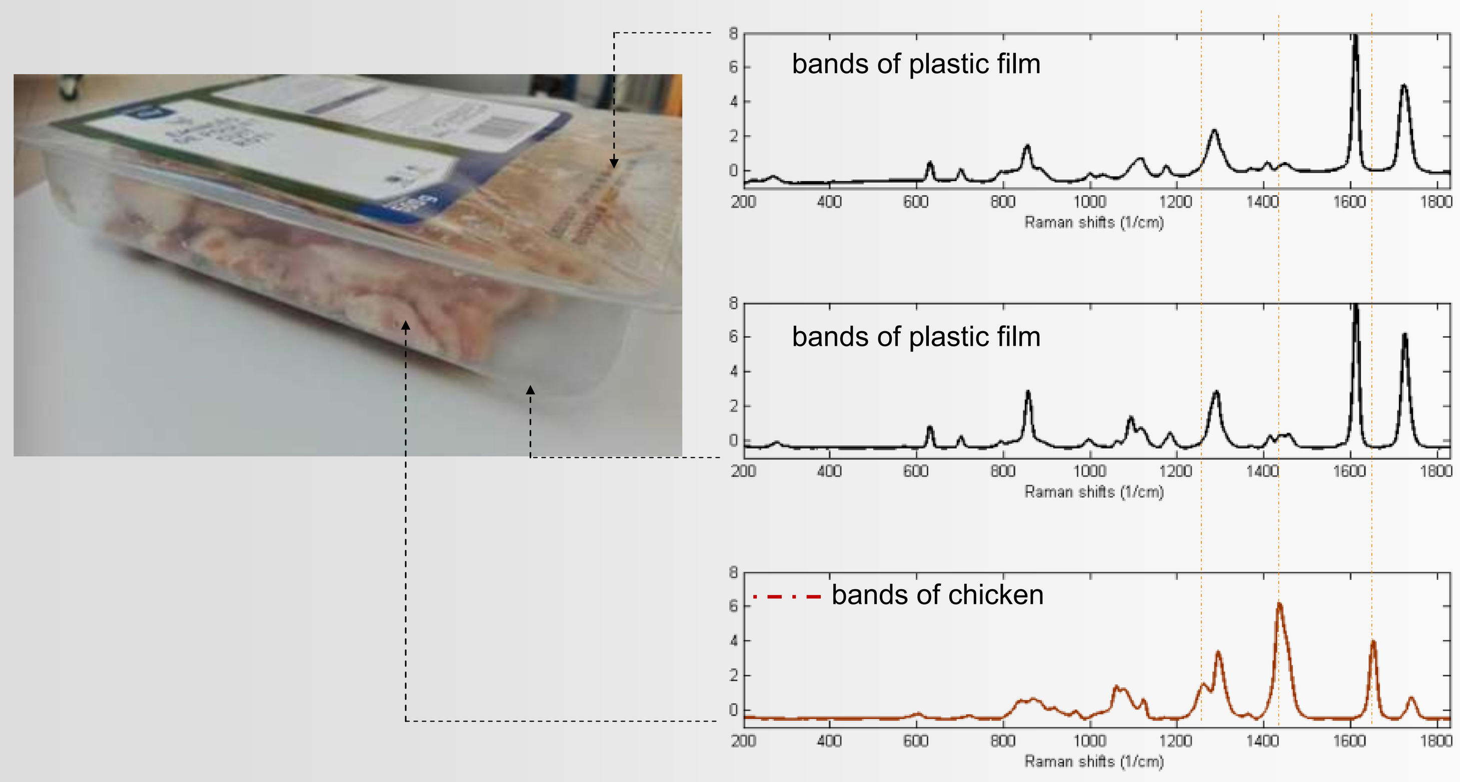
Adapting Raman sensor for the refrigerated transport

A portable device is currently used for the analysis of food without removing of the packaging film.

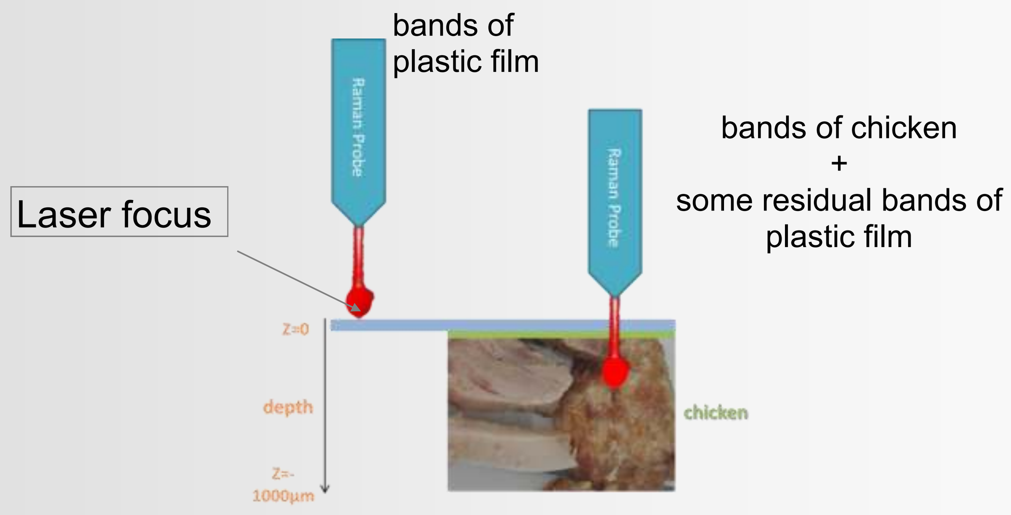


Portable Raman spectrometer with optical probe for the analysis of food during transport

The preliminary experience shows the possibility to analyze the food samples directly inside the container. Nevertheless, the exploration of results reveals the overlapping between chicken bands with some Raman signals of the packaging plastic film.



The packaging impacts the Raman signal of chicken. Currently, we work on the optimization of analysis protocol to eliminate this impact .The focalisation of laser spot behind the film allows to have a signal specific to chicken, an mathematical algorithm is still necessary to eliminate bands of the plastic packaging (under construction).



Conclusion

Raman spectroscopy revealed the impact of storage temperature on chicken samples and allowed to classify properly the samples according to their storage conditions. The use of portable device add more challenges for the analysis of packaged food. The combination between optical and mathematical solutions is necessary to eliminate signal of the packaging. The ultimate step is to integrate the Raman sensor directly into a refrigerated truck and to test it under real conditions.

WD Meats – Pilot Tests

Pilot-test start date: March 2020

Interreg North-West Europe REAMIT

www.reamit.eu

We are REAMIT

REAMIT is a transnational territorial cooperation project funded by Interreg North West Europe (NWE) Programme aiming to reduce food waste. The project focuses on fruits, vegetables, meat and fish supply chains as these are wasted in large quantities. It is carried out in Ireland, Germany, France, UK and the Netherlands due to the amount of interconnected food supply chains and huge food waste in these countries.

The REAMIT project is using existing Internet of Things and Big Data technologies to best fit the needs of the food supply chain management system in the NWE region. Through testing and adaptation, these technologies are being enabled to continuously monitor and record food quality and signal potential food quality issues. Through analytics, owners of 'food to be at risk of becoming waste' are provided with decision support options to minimise food waste including redistribution to nearby customers. As part of the technology demonstrations (aka pilot tests), the REAMIT project team is working with WD Meats on two different activities, helping to reduce waste of beef meat.

Who is WD Meats in food sector?

WD Meats, based in Coleraine, Northern Ireland is a Beef Manufacturer since 1979. It provides a high-quality beef with full traceability of meat and livestock. WD Meats supplies beef to a wide range of retailers and other food services across the UK and Europe, as well as to markets in Asia and Africa. WD Meats also makes regular supply to various food services outlets such as catering butchers, independent retailers and as well as wholesalers.

REAMIT-WD Meats-Ulster University collaboration

Ulster University, one of the partners in the REAMIT consortium, is working closely with WD Meats on two pilot tests. One approaches the global food waste phenomenon known as "blown pack spoilage" (BPS) and the other investigates the impact temperature gradients can have on beef within dry-aging chambers.

How to prevent the spread of bacteria in the meat products?

BPS prevention trial : The occurrence of BPS is caused by several strains of the Clostridium bacteria, most notably Clostridium Estertheticum. Presence of this anaerobic bacteria within typical vacuum sealed packaging can result in notably reduced shelf life and an inevitable increase in wasted beef. Rapid detection of this bacteria could not only prevent the spread, but also, as it is a non-toxic bacteria, it could stop infected meat from being wasted by not giving the bacteria chance to reproduce. REAMIT sensor technology will be used to rapidly identify samples containing the virus and allow for the product removal and immediate sanitisation of exposed areas.

Dry-Aging trial : Due to the configuration of dry-aging 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. REAMIT will add a number of Ursalink UC-11 IoT-connected LoRaWAN temperature and humidity sensors to these chambers and analyse the outputted data against the meat produced.

Why REAMIT for WD Meats?

Current challenges of WD Meats	REAMIT technology for WD Meats	Objectives of REAMIT-WD Meats pilot test
Clostridium contamination through slaughtering process can result in huge loss of spoiled product.	✓ 3D Fluorescence sensors ✓ Internal on-site laboratory ✓ Tempo system for identifying bacteria counts on raw beef products ✓ Internal Swabbing system for detection of clostridium esters with external testing lab	**Clostridium trial** ✓To identify if the bacterium is present ✓To give a quick turnaround to help identify the problem ✓To isolate the contaminated product before carrying out full clean downs on affected areas
When process drift from set points, this can have a detrimental effect on yield, spoilage & and eating quality of finished products.	Company has been dry-aging meat produce for years. **REAMIT offers:** On-site Dry aging chambers and state of the art dry-ageing chillers.	**Dry-ageing trial** ✓To increase the monitoring capability of the relative humidity and temperature ✓To result in reduced yield-loss without affecting eating quality

REAMIT-WD Meats Collaboration output

Collaborative efforts between WD Meats and Ulster University on the REAMIT project, promise to save a substantial amount of food. For instance, experience shows that an unprepared facility, experiencing an issue with the BPS causing Clostridium Esterthéticum can result in approximately 7,800 kg of wasted beef per year. Early warning with REAMIT sensors is helping to avoid 25-50% of this waste so far, equivalent to 2,000-4,000 kg of meat saved or approximately £25,000 per year. In addition to this saving, the REAMIT project is saving much more meat waste- by providing optimal conditions through REAMIT technology, WD Meats will enhance the quality of the meat produced, which will make huge savings on resources and save meat products becoming waste.

The REAMIT consortium is looking for agri-food companies in North West Europe to demonstrate food waste reduction through its approach and technology. Do you think your company could benefit from REAMIT approach and technology? If you want to be more efficient with your resources, REAMIT can equip you with necessary tools to save you time and resources, and in the long-term to reduce food wastage locally and globally!

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RESOURCE & MATERIALS EFFICIENCY

Biogros and the REAMIT Project

Pilot-test start date: November-2021

https://www.biogros.lu

We are REAMIT

REAMIT is a transnational European territorial cooperation project funded by Interreg North-West Europe (NWE) Programme aiming to reduce food waste. The project focuses on fruits, vegetables, meat, and fish supply chains as these are wasted in large quantities. It is being carried out in Ireland, Germany, France, UK and the Netherlands due to the amount of interconnected food supply chains and huge food waste in these countries. The REAMIT project is using existing Internet of Things and Big Data technologies to best fit the needs of the food supply chain management system in the NWE region. Through testing and adaptation, these technologies are being enabled to continuously monitor and record food quality and signal potential food quality issues. Through analytics, owners of 'food at risk of becoming waste' are provided with decision support options to minimise food waste including redistribution to nearby customers. As part of the technology demonstrations, the REAMIT project team is working with Biogros, helping to reduce food waste.

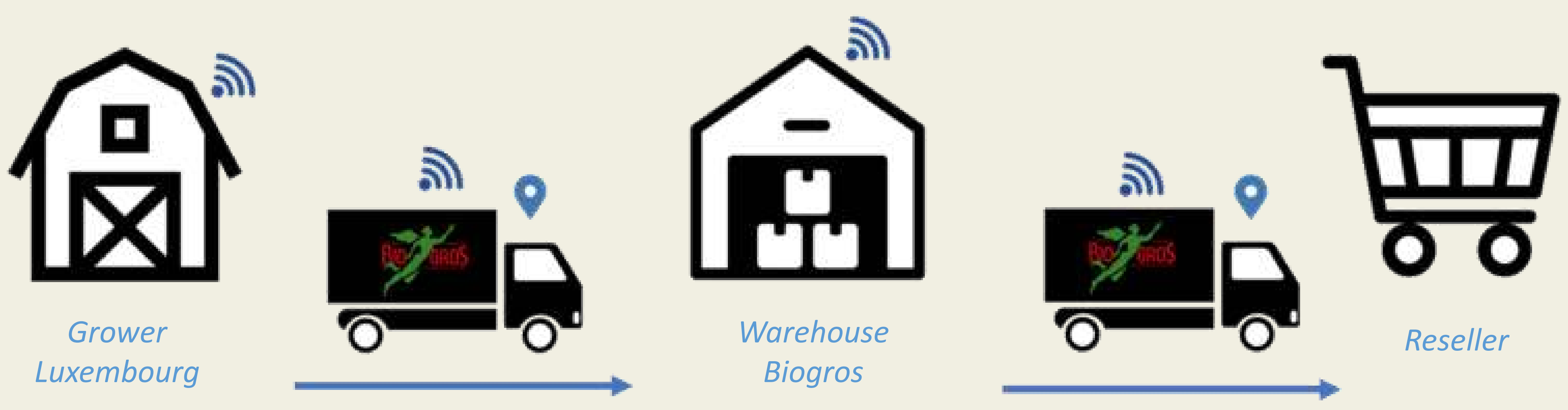
We are Biogros

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 our close collaboration with organic farmers from the cooperative Bio-Bauern-Genossenschaft Lëtzebuerg (BIOG), who also offer a whole range of regional organic products.

Challenges 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 wanted to gain insight in the climatic conditions (temperature and humidity) in the full supply chain, from grower to supermarket. Biogros sought a system which would perform the following:

1. The trucks should be connected to the cloud to allow for real-time data reporting / monitoring while the trucks perform deliveries
2. The warehouses of both grower and Biogros should be connected to the cloud, measuring temperature and humidity to allow for real-time data reporting/ monitoring
3. An alerting system should send SMS messages to drivers and warehouse logistics staff notifying if any anomalies occur
4. Alerts should not be sent when the trucks are stationary e.g., parked overnight, performing a delivery, etc.
5. The power consumption of the proposed system should be such that maintaining the equipment does not become an arduous task

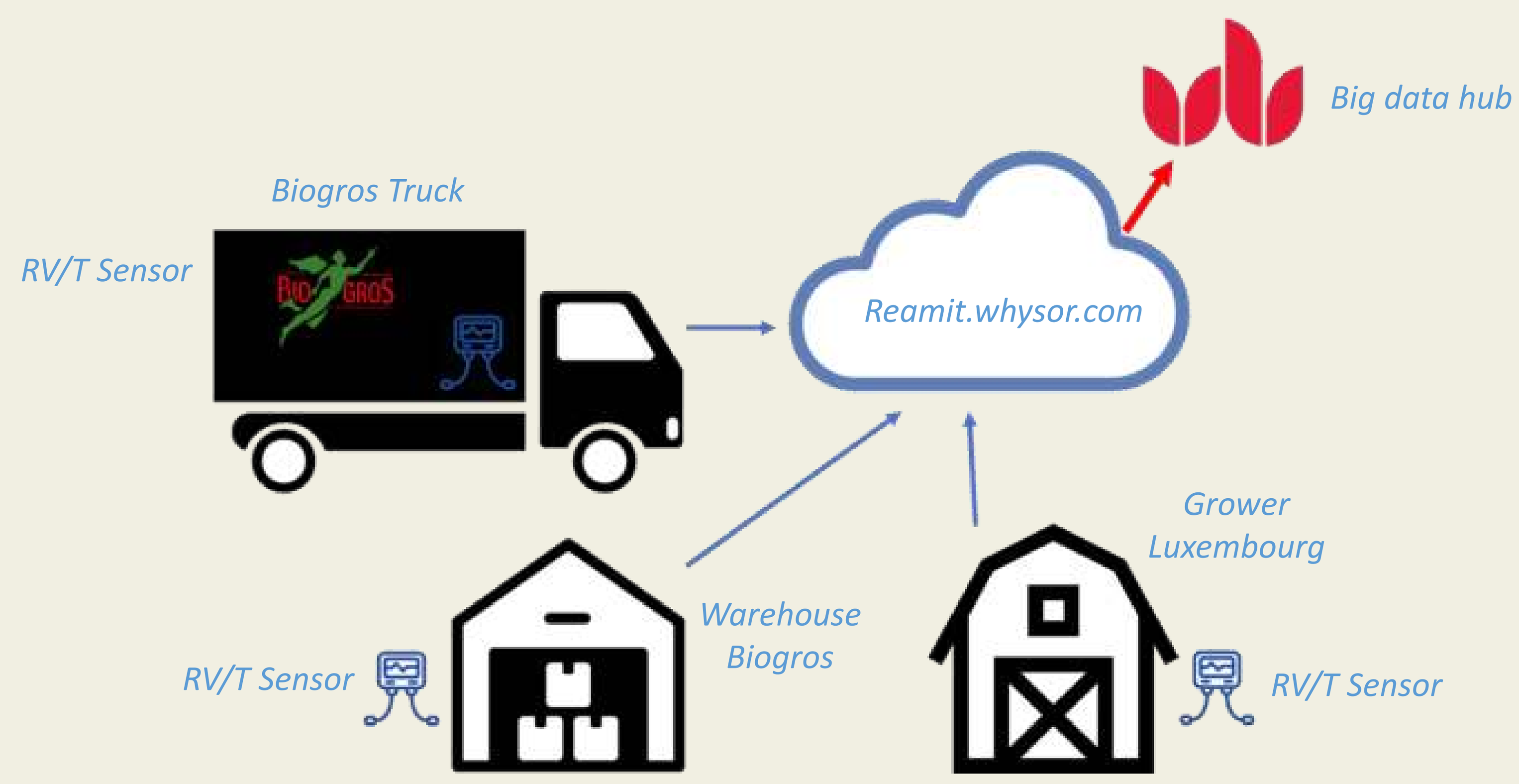


REAMIT's solution

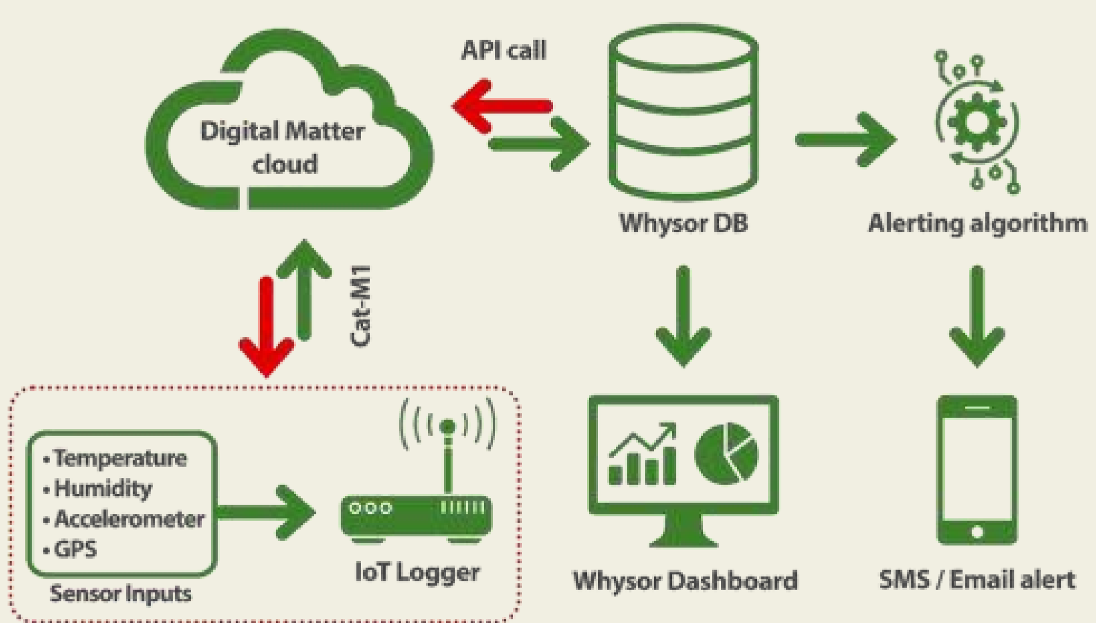
The REAMIT team at Whysor (the Netherlands) examined Biogros' system requirements and proposed a real-time monitoring and alerting system for anomaly detection during the full supply chain. The Eagle datalogger (Digital Matter, South Africa) was selected as the platform for the development of the REAMIT solution. The logger is an IP67 rated rugged cellular IoT device, supporting a range of inputs for various IoT applications. The Eagle runs on either batteries or can be wired to permanent power. It has analog, digital and serial inputs. It contains a GPS module and an accelerometer for geofencing and movement detection and is equipped with a sim card allowing the device to perform as an IoT gateway, running on the GPRS LTE / 4G network.

For the Biogros pilot, the logger was fitted with a T9602 Temperature/Relative Humidity sensor (Amphenol, USA), to allow monitoring in ambient and chilled zones of trucks and warehouses.

Whysor developed the REAMIT dashboard for real time monitoring and alerting, which was utilized by each pilot study in the project. The dashboard runs on both desktop computer and smartphone. The alerts can trigger an e-mail or SMS notification.



System Architecture



Alerting logic. The threshold values for the alerting system are defined by the technical team at Biogros, for all locations inside the warehouse or inside the truck. Text messages are sent if the limit value is exceeded, e.g., above 8°C in the vegetable department or above 10°C inside the truck.

To avoid false alerts, the system records 2 consecutive values above the threshold before sending the alert. The values are recorded every 5 minutes by the logger.

Trip detection. A trip detection algorithm was developed based on accelerometer measurements and GPS data reported by the Eagle logger. A trip would be reported if motion was detected by the accelerometer and if the GPS coordinate had changed from the previous reading. This algorithm allowed the system to sleep when trips are not being performed to conserve battery life, as well as avoiding sending false alerts while trucks are parked overnight.

Results and Conclusion

The IoT anomaly detection system was deployed in Biogros between March-July 2022 in nine trucks, at three growers and at seven departments inside the Biogros warehouse. Logistics staff at the warehouse were given access to the REAMIT dashboard for real-time monitoring of the vehicles and warehouses and were added to the alerting service. This allowed them to receive text messages to their smartphone if an anomaly was detected. Early results show that the system is robust and avoids sending false alerts due to the trip detection algorithm, a purpose-built customised system.

Practical application. We have developed an IoT solution which monitors in real time the temperature and humidity of the full supply chain.

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RESOURCE & MATERIALS EFFICIENCY

Picnic and the REAMIT Project

Pilot-test start date: November 2020

PIC NIC

https://picnic.app/nl/

We are REAMIT

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We are Picnic

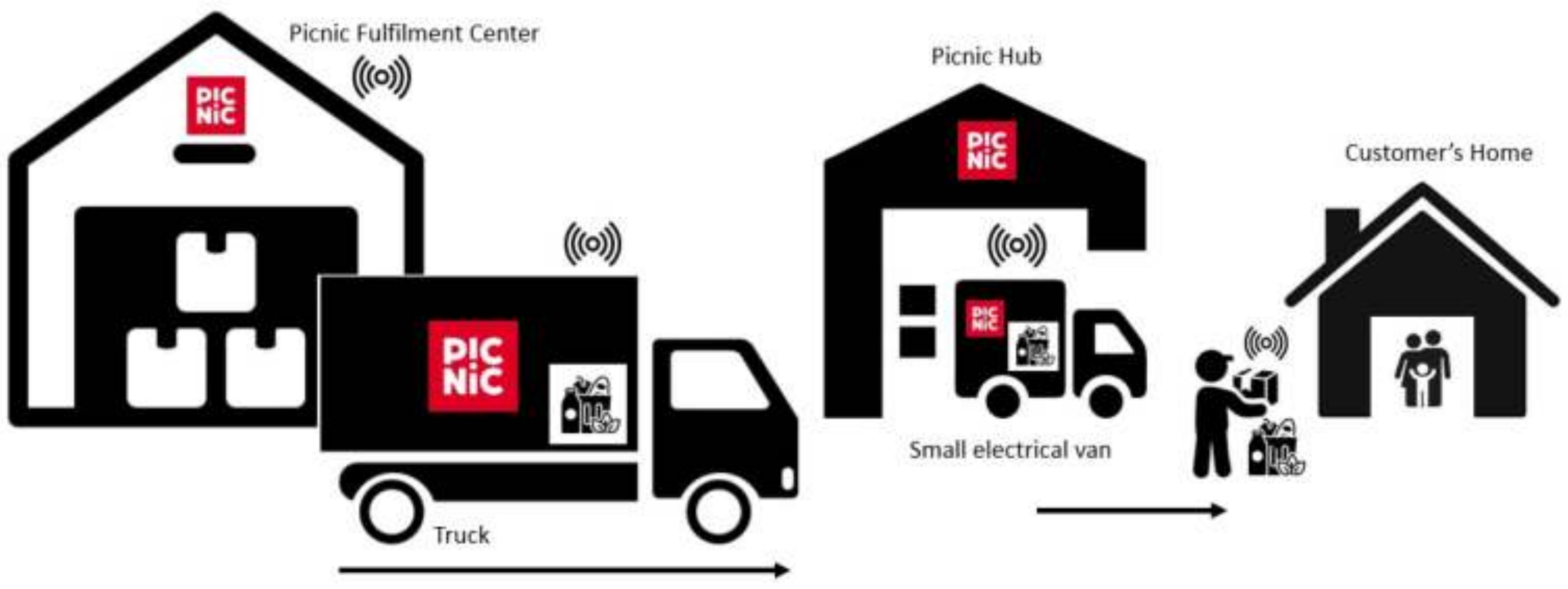
Picnic was founded in the Netherlands in 2015 and started with 4 delivery vans. In 2022 more than 1,000 electrical vans drive around in about 120 Dutch cities. With hundreds of thousands of customers and a monthly expansion to new cities, Picnic was named the fastest growing company in the Netherlands 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.

Challenges at Picnic

Based on the Picnic data driven weather regime, Picnic decides daily how many icepacks 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 center 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:

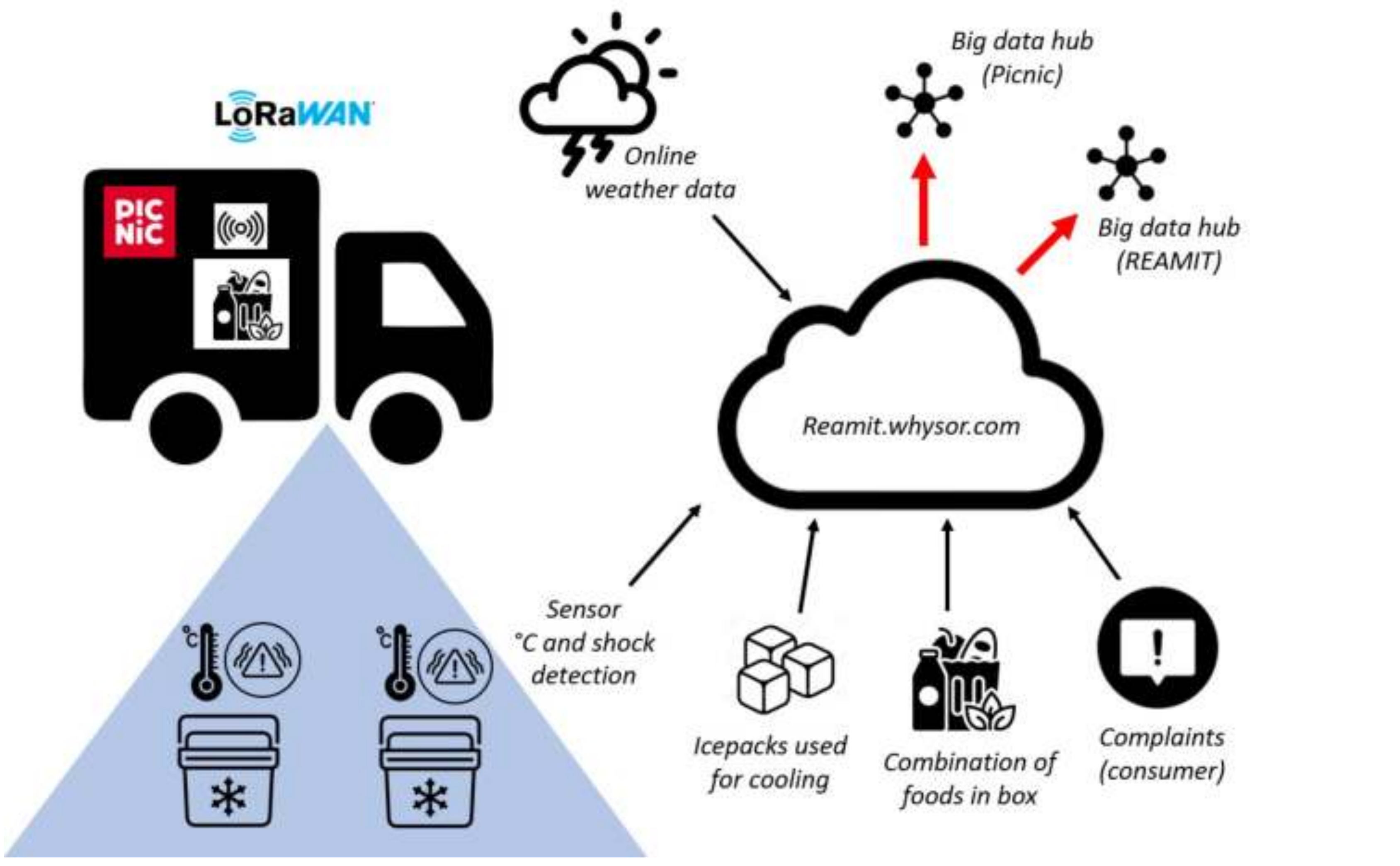
1. The boxes should be connected to the cloud to allow for (near) real-time data reporting / monitoring while the boxes are being transported.
2. The sensor housing should be able to withstand forces of heavy groceries and differences in temperature and humidity.
3. Development of a personalized cooling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



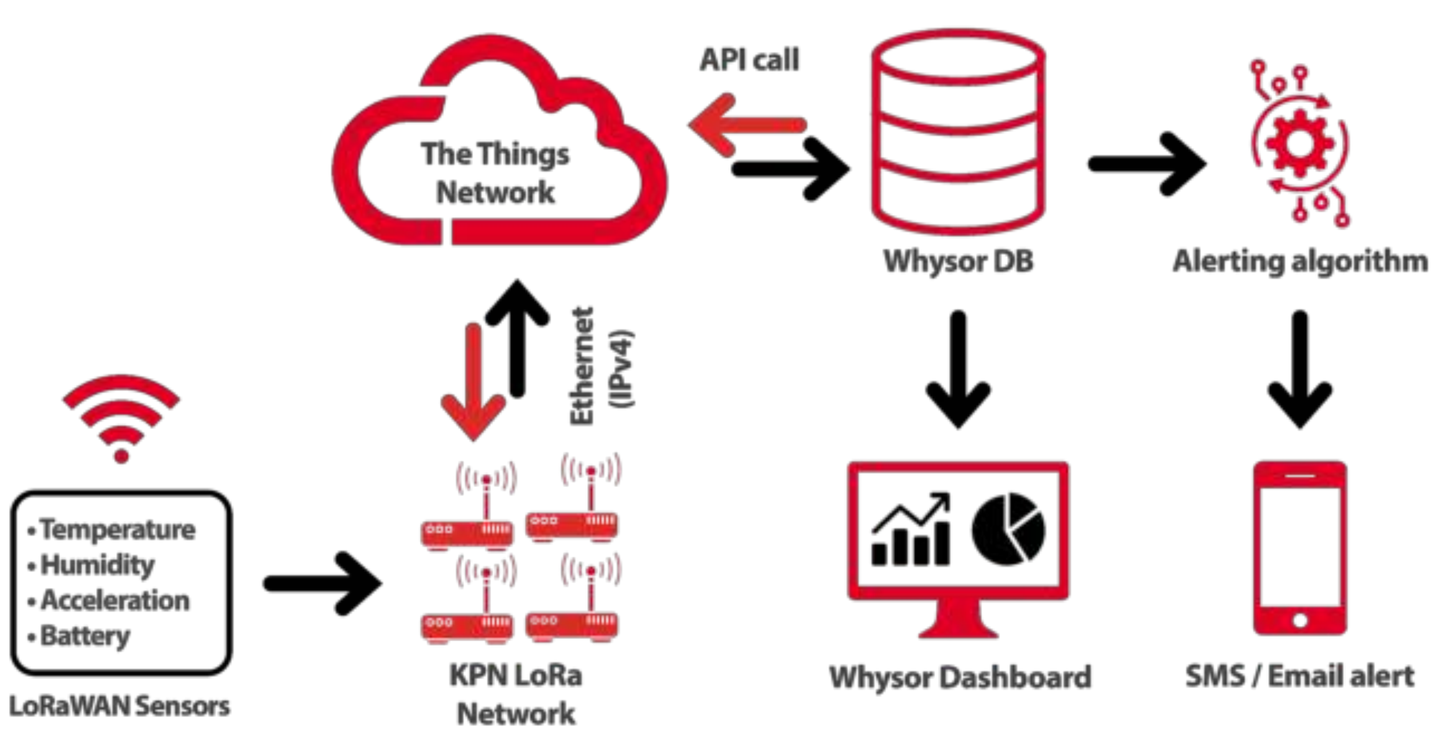
REAMIT's solution

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 complete transportation process of cooling boxes. The EMS sensor (Elsys, Sweden) was selected as the sensor of choice to measure temperature and humidity. 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). The EMS is connected to the cloud by the LoRaWAN network, provided by KPN in the Netherlands.

Whysor developed the REAMIT dashboard for real time monitoring and alerting, which was utilized by each pilot study in the project. The dashboard runs on both desktop computer and smartphone. The alerts can trigger an e-mail or SMS notification.



System Architecture



Sustainable sensor housing. After the first testing period with the EMS sensor, the REAMIT team noticed that the original housing of the sensor was not sustainable enough to withstand the heavy forces of groceries inside the box. The team developed several prototypes of 3D-printed flexible rings to better protect the sensor.

Power consumption. The EMS sensors are configured to send data every 10 minutes. A lower transmission speed has been chosen because there is no consistent signal quality in the trucks. With the current configuration of the sensors, battery life is expected to be 1-2 years.

First conclusions

Conclusions after first and second testing round

1. 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.
2. 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.
3. The tracing of sensors that are not working needs more research because of the complexity of the Picnic box routing method.

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Reducing Food Waste during the Dry Ageing of Beef using IoT Technology

REAMIT Pilot study with Burns Farm Meats

Cama-Moncunill, X.[1], Da Costa, T.[1], Murphy, F.[1], Ward, S.[1], Gillespie, J.[2], Ramanathan, R[3]. http://reamit.eu

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We are REAMIT

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Who are Burns Farm Meats?

Burns Farm Meats Ltd. is a long-established family-owned company located 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.

Burns Farm Meats are especially interested in the monitoring of the dry-ageing process. In fact, despite increasing the flavour and tenderness of the meat, it is still a costly process for abattoirs because of shrinkage of the meat, trim loss, and risk of contamination

Challenges at Burns Farm Meats

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

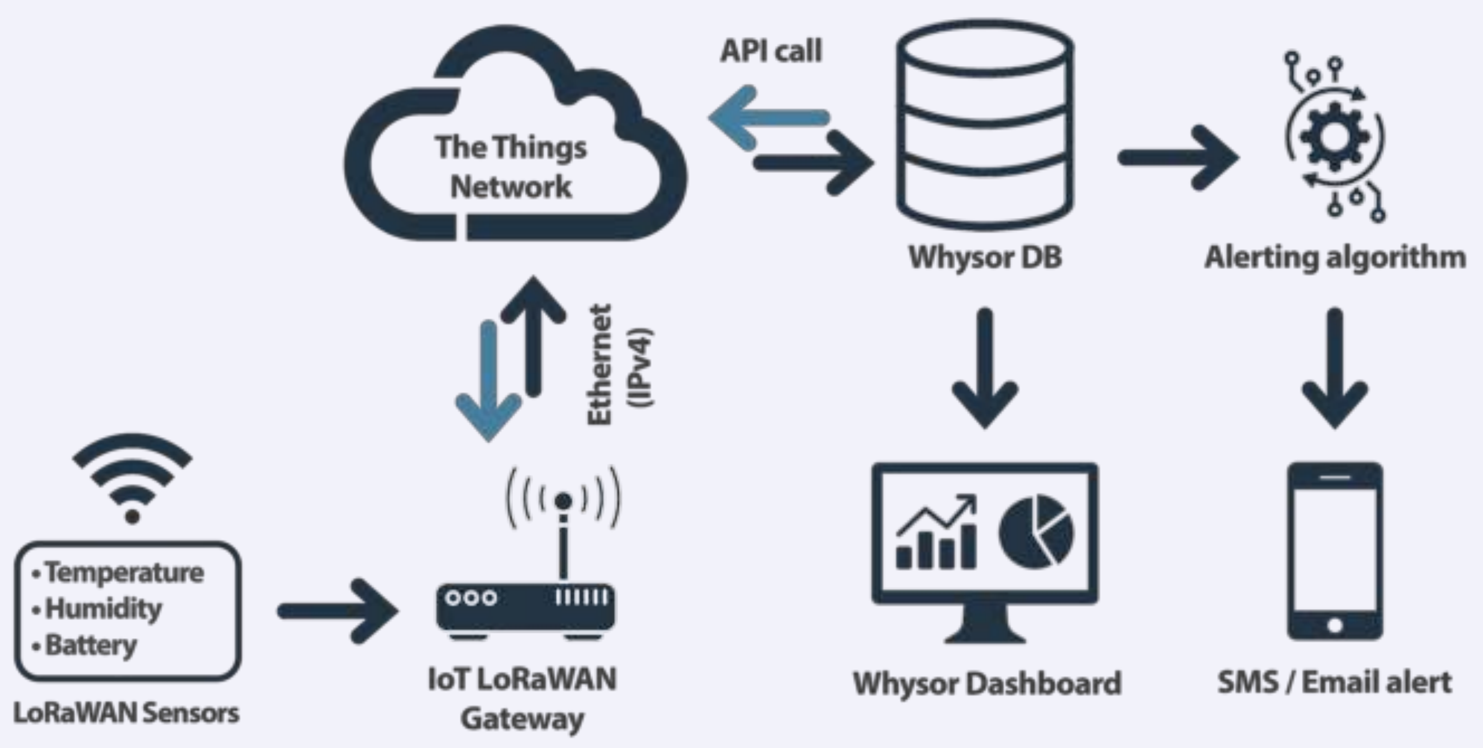
REAMIT's solution

The REAMIT team at University College Dublin evaluated the system requirements by Burns Farm Meats and proposed a real-time monitoring and alerting system for anomaly detection during dry ageing of beef. The ELT-2 Internal antenna (Elsys, Sweden) was selected as the platform for the development of the REAMIT solution. The ELT-2 is enclosed in an IP67 rated box which makes it suitable for extreme conditions. While it is possible to connect external sensors to the ELT-2, it already contains four built-in internal sensors, including temperature and humidity, which will be employed for monitoring of the environmental parameters in the dry-ageing chambers. An ELT-2 is powered by one 3,6V AA lithium battery and has an expected battery life of <10 years (subject to environment and configuration).

For the Burns Farm Meats pilot, we fit several ELT-2 Internal antenna sensors in two refrigerated chambers spatially distributed in such a way, that allows for collecting data from different areas: closer to doors, closer to the refrigeration unit, and in between the former two. The ELT-2 sensors transmit data through LoRa communication signal to a gateway device, a Tektelic Kona Micro IoT Gateway (Tektelic, Canada), which in turns sends the data to The Things Network cloud via an internet connection.

REAMIT partners Whysor (Netherlands) developed the REAMIT dashboard for real-time monitoring and alerting, which was utilized by each pilot study in the project. The dashboard runs on both desktop computer and mobile phone. SMS alerting was provided by Amazon Simple Notification Service (SNS).

System Architecture



Alerting logic. The threshold values for the alerting system were defined by Burns Farm Meats and UCD. Text messages are sent if the temperature in the chambers reach temperatures higher than 7ºC.

Results and Conclusion

The IoT temperature and humidity monitoring system was deployed with Burns Farm Meats in September 2022 in two dry-ageing chambers at their abattoir. The system provides real-time environmental condition logging of the fridges. The owners of Burns Farm Meats were given access to the Whysor dashboard for real-time monitoring of the fridges and were added to the alerting service. This allowed them to receive text messages to their mobile phones if an anomaly was detected. After more data is recorded, the REAMIT team will keep on performing analysis and provide recommendations as to how Burns Farm could minimise beef loss during their dry age.

Conclusion. We have developed an IoT solution which monitors in real time the temperature and humidity of dry ageing chambers at an abattoir. The end-to-end solution provides decision support options if anomalies are detected, helping staff correct any issues and thus reducing the spoilage and waste of food. Future work will focus on improving the proposed IoT system and identifying the underlying causes of loss of quality of beef in dry ageing chambers to minimise waste and increase efficiency even further.

Additional Information

[1]University College Dublin, Dublin, Ireland
[2]Ulster University, Northern Ireland, United Kingdom
[3]University of Essex, Southend-on-Sea, United Kingdom

For further information about the REAMIT project, please visit http://reamit.eu

Real Time Anomaly Detection in Cold Chain Transportation using IoT Technology

REAMIT Pilot study with Musgrave Marketplace

Gillespie, J.[1], Cadden, T.[1], Condell, J.[1], Ramsey, E.[1], Gallagher, R.[2], Ramanathan, R[3]. http://reamit.eu

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Who are Musgrave?

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 have estimated annual sales of over €4 billion. The company is still largely-owned by the Musgrave family. Musgrave Northern Ireland is headquartered in Belfast, Northern Ireland. Musgrave clients include local restaurants, fast-food outlets, and convenience shops in Northern Ireland, and also operate multiple large cash and carry facilities for the general public. Musgrave maintain their own fleet of delivery vehicles to facilitate deliveries to their business customers.

The Problem at Musgrave

While performing deliveries to their business customers, Musgrave noticed that the refrigeration units in the delivery vans operating in the greater Belfast area would occasionally break down, without any indication to either the driver or the logistics staff at the warehouse. The temperature of the chilled and frozen food products inside the van would increase, surpassing the food storage temperature safety threshold, resulting in a van load of spoiled stock. Musgrave sought a system which would perform the following:

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

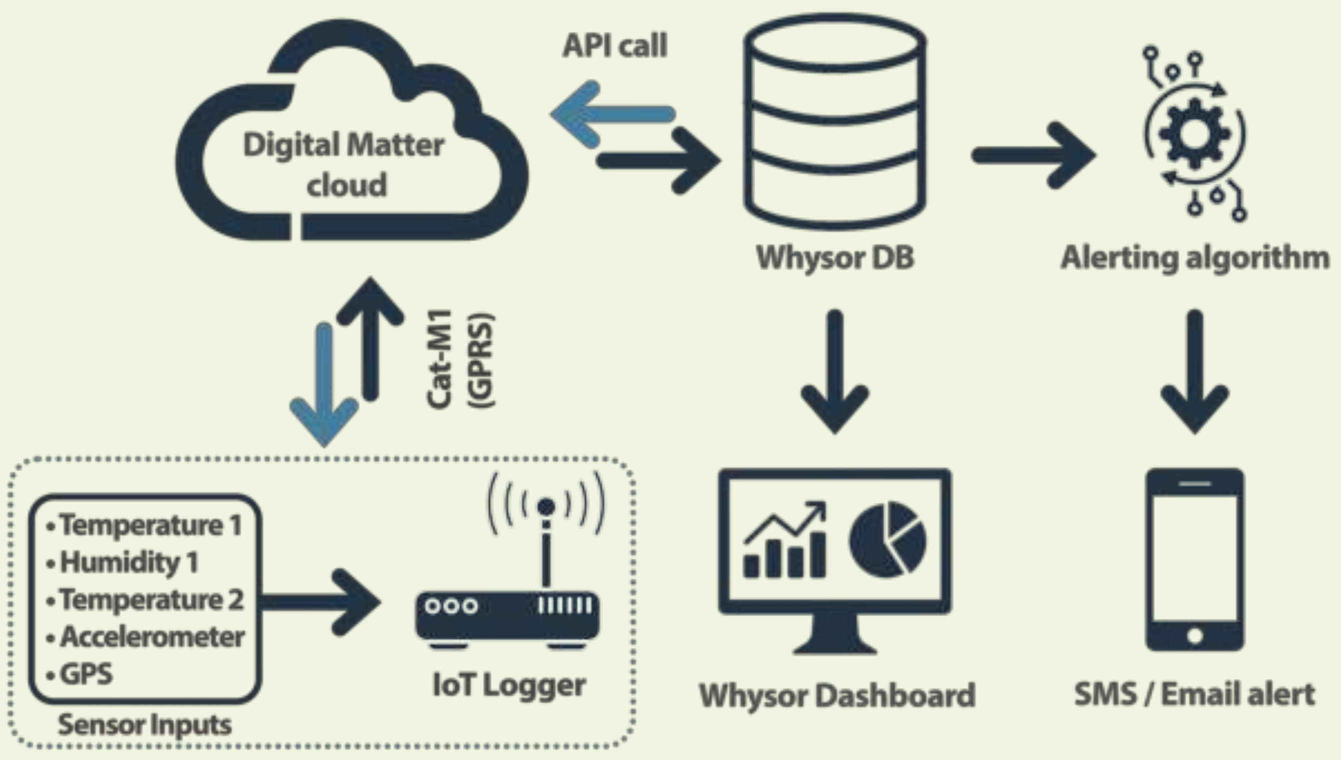
REAMIT's solution

The REAMIT team at Ulster University examined the system requirements by Musgrave and proposed a real-time monitoring and alerting system for anomaly detection during cold-chain transportation. The Eagle datalogger (Digital Matter, South Africa) was selected as the platform for the development of the REAMIT solution. The logger is an IP67 rated rugged cellular IoT device, supporting a range of inputs for various IoT applications. The Eagle runs on either 4x C Alkaline or LTC batteries, or can be wired to permanent power, and contains I2C, SDI-12 and RS-485 interfaces as well as 2x analogue inputs, 3x digital inputs, 2x switched ground inputs, and 2x 4-20mA inputs. It contains a GPS module and an accelerometer for geofencing and movement detection, and is equipped with a sim card allowing the device to perform as an IoT gateway, running on the CAT-M1 GPRS network. The Eagle offers third party cloud integration via HTTPS webhook.

For the Musgrave pilot, we fit the logger with a T9602 T/RH I^2C sensor (Amphenol, USA), and a DS18B20 temperature probe (Maxim Integrated, USA) to allow monitoring in both chill and freeze zones of the van.

REAMIT partners Whysor (Netherlands) developed the REAMIT dashboard for real time monitoring and alerting, which was utilized by each pilot study in the project. The dashboard runs on both desktop computer and mobile phone. SMS alerting was provided by Amazon Simple Notification Service (SNS).

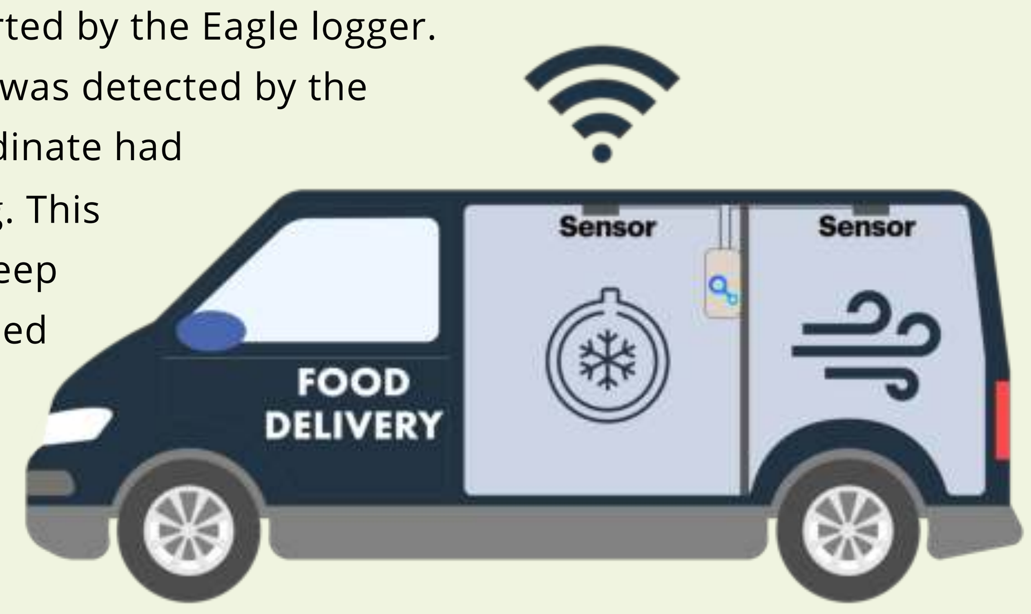
System Architecture



Alerting logic. The threshold values for the alerting system were defined by the logistics and warehouse manager at Musgrave. Text messages are sent when the van is performing a delivery and either the chill zone rises above 5ºC, or the freeze zone rises above -8ºC. To avoid false alerts, the system records 6 values above the threshold before sending the alert. The values are recorded every 5 minutes by the logger.

Trip detection. A trip detection algorithm was developed based on accelerometer measurements and GPS data reported by the Eagle logger.

A trip would be reported if motion was detected by the accelerometer and if the GPS coordinate had changed from the previous reading. This algorithm allowed the system to sleep when trips were not being performed to conserve battery life, as well as avoiding sending false alerts while vans were parked overnight.



Results and Conclusion

The IoT anomaly detection system was deployed with Musgrave Marketplace in April 2022 in three delivery vans operating in the greater Belfast area. The system monitors both the frozen and fresh produce refrigeration areas of each van in 5-minute intervals while deliveries are being performed. Logistics staff at the warehouse were given access to the Whysor dashboard for real-time monitoring of the vehicles, and were added to the alerting service. This allowed them to receive text messages to their mobile phone if an anomaly was detected. Early results show that the system is robust and avoids sending false alerts due to the trip detection algorithm which was developed. At the time of writing (July 2022), the batteries have not needed replaced in the loggers yet, proving that the bespoke system developed with trip detection technology is energy efficient and of minimal maintenance. After successful initial testing, two more of the IoT temperature monitoring systems have been prepared and are due to be installed in Summer 2022.

Conclusion. We have developed an IoT solution which monitors in real time the temperature of cold chain delivery vehicles transporting perishable items. The end-to-end solution provides decision support options if anomalies are detected, helping staff redirect the delivery to a closer drop-off point and thus reducing the spoilage and waste of food.

Additional Information

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For further information about the REAMIT project, please visit http://reamit.eu