Final Report

WP3.2: In-Factory Asset Tracking

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1	Initial issue

About 5G-Encode

The 5G-ENCODE Project is a £9 million collaborative project aiming to develop clear business cases and value propositions for 5G applications in the manufacturing industry. The project is partially funded by the Department for Digital, Culture, Media and Sport (DCMS), of the UK government as part of their 5G Testbeds and Trials programme.

The key objective of the 5G-ENCODE project is to demonstrate the value of 5G on industrial use cases within the composites manufacturing industry. It will also validate the premise that using private 5G networks in conjunction with new business models can deliver better efficiency, productivity, and a range of new services and opportunities that would help the UK lead the development of advanced manufacturing applications.

The project showcases how 5G features such as neutral hosting and network slicing can be applied to transform a private 5G network into a dynamically reconfigurable network able to support a wide range of applications (URLL/eMBB/MMTC) including industrial applications of Augmented Reality/Virtual Reality (AR/VR), asset tracking of time sensitive materials and automated industrial control though IoT monitoring and big data analytics. Such a dynamic network is expected to enable new business models and creation of bespoke virtual networks tailored to specific applications or use cases.

The state-of-the-art test beds were deployed across three sites, centred around the National Composites Centre (NCC) in the southwest of England. In support of the West of England Combined Authority (WECA) industrial strategy, the NCC plans to keep the test bed as an open access facility for the experimentation and development of new products and services for the composites industry after the completion of the 5G-Encode project.

The project consortium brings together a Tier 1 operator (Telefonica), leading industrial players (e.g. Siemens, Toshiba, Solvay), disruptive technology SMEs (Zeetta Networks, Mativision, Plataine), application performance as measured by probes (Accedian), world-leading 5G network research group (High Performance Networks Group in the University of Bristol) and the NCC representing the high value manufacturing industry.

Executive Summary

An autonomous asset tracking solution, as the one proposed by this use case, offers the opportunity to effectively track mobile tools and assets such that current unproductive time spent searching for these items is minimised. When applied to time sensitive materials, such as prepreg carbon composites, this solution could also reliably monitor product out-life and a tooling maintenance schedule to minimise material wastage and ensure representative product traceability information, as well as high quality manufacturing standards of components.

The use case evaluated in this report encompasses key features, typical of an automated fibre placement process – a high value manufacturing method to produce composite parts, as well as post processing operations (e.g. curing, non-destructive testing, metrology scanning).

The proposed asset tracking solution relies on both software and hardware components, with the existing sensor gates deployed on the NCC factory floor communicating real time data to a live web application via a 4G, 5G or wired power over ethernet (POE) connection.

Based on the 4G asset tracking baseline findings, it was concluded that the performance of the test bed was directly linked to the network stability. 5G technology showed the potential to enhance the asset tracking solution by enabling connectivity to a much wider range of devices and assets simultaneously, without compromising its stability, offering improved speeds and latency.

This digital asset tracking solution showed great benefits in the form of productivity improvement, cost savings and better tooling control. By ensuring easy access to real time asset location information, it is possible to more efficiently plan a manufacturing schedule based on asset availability, minimising the unproductive time spent on searching and locating tooling or materials as production commences. It has been assessed that a 93% reduction in search time per job is possible with the present asset tracking solution, removing the likelihood of rescheduling a production run due to item unavailability.

Another major benefit of the proposed asset tracking solution is the ability to closely monitor stock life and availability, leading to an improved stock management and minimal

material wastage, with implicit cost savings of at least £56,000 per year for production facilities similar in size and manufacturing rates to the NCC. Also, by closely monitoring the usage of tooling in production cycles, it is possible to reliably record and schedule maintenance, and, thus, ensure a high-quality standard of production.

The asset tracking technology detailed in the present report showed to be an effective means to wirelessly monitor both item location and material out-life in a production environment, but for a relatively small number of products. It is of interest for this use case to explore further the 5G capabilities for asset tracking and assess how a higher number of assets managed by the system would impact the performance and accuracy of the test bed. Seeking an out-of-factory tracking solution is also a scope of work the NCC would like to trial in the near future; however, access to public or private 5G networks outside production facilities is a prerequisite.

Contents

List of Figures

List of Tables

Abbreviations

4G LTE	Fourth Generation Long-Term Evolution
5G	Fifth Generation
AFP	Automated Fibre Placement
AI	Artificial Intelligence
AT	Asset Tracking
CPE	Customer Premises Equipment
IoT	Internet of Things
MES	Manufacturing Execution system
NCC	National Composites Centre
NDT	Non-destructive Testing
POE	Power over Ethernet
Plataine TPO	Plataine Total Production Optimisation
RF	Radio Frequency

1. Introduction

1.1 Aims and Objectives

In a manufacturing environment, there is a high likelihood that there will be time wasted when locating resources and equipment that could potentially lead to a loss in productivity or a reduction in profits. Thus, asset tracking in any form can be an invaluable tool to help businesses operate safely and effectively, while ensuring the highest standards.

Consequently, a proposition for a wireless asset tracking solution was made that included the ability to closely track assets in a production facility – from material and tooling, to finished parts and equipment – while monitoring time sensitive properties of the material from manufacturing through to use in production. Ultimately, a digital passport of the component would be generated to ensure traceability of material and tooling data.

The present use case was based on an automated fibre placement (AFP) manufacturing workflow; the process being in line with the Preform – Cure – Verify composite manufacturing cycle. An AFP process was chosen as the manufacturing process for the simple reason that it is a relevant production method to high value manufacturing (HVM) employed across a range of sectors – from Aerospace and Defence, to Automotive and Energy industries.

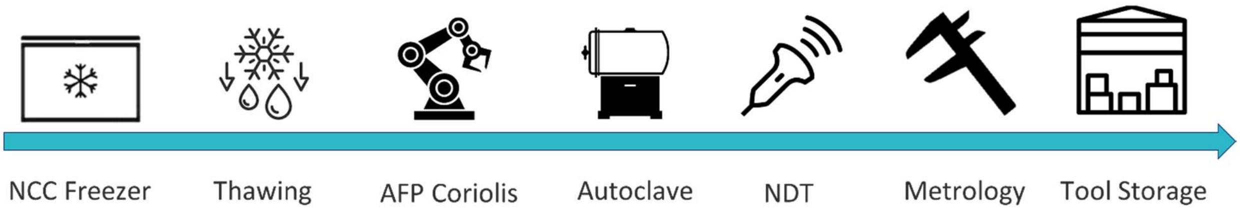


Figure 1 Factory movement flow corresponding to the respective RFID stations

However, the remaining stations in the manufacturing workflow (e.g. Freezer, Thawing, Autoclave, NDT, Metrology and Tool Storage) remain representative for any manufacturing process (i.e. automated or manual); thus, making the proposed asset tracking solution easily adaptable to other production methods or workflows.

An automated fibre placement process is an autonomous machine-driven manufacturing method that implies costly specialised equipment, tooling and material stock. Thus, it is of essence for such expensive and complex production processes that tooling and raw materials are delivered to the required standard to ensure both product and equipment quality.

Numerous composite materials have limited shelf lives, requiring special storage conditions at -18°C to preserve their high-performance characteristics. Thus, the material work life and, implicitly, its performance are highly dependent on the experienced exposure time to room temperature conditions. Typically, this information is recorded manually by technicians, operators or engineers, being rather an estimate than a representative value. It is therefore critical to ensure that the material is still in-life to guarantee certain component performance characteristics (i.e. mechanical properties).

Similarly, monitoring tool maintenance and ensuring its appropriate storage when not in use is key to guarantee the quality of tool and, implicitly, the performance of the final component. Considering the implicit costs of producing a component using an AFP process, it is of even greater importance to minimise potential causes of defects during manufacturing due to outdated material stock or defective tooling.

Consequently, the engineering challenge that this use case identified within the context of high value manufacturing was the absence of reliable in-factory asset tracking methods that could provide accurate item location, availability and out-life/maintenance information.

The principal aim was to demonstrate the ability of this solution to provide accurate live location information of the tagged assets. It was of great importance for this application for the location to be accurate enough to enable users to quickly identify the item.

Also, the main objective for this use case was to design and implement a wireless in-factory tracking system for an automated fibre placement process. The system functionalities were tested and measured against 4G and 5G test bed capabilities, to determine the ability of 4G LTE and 5G to drive the intended use case business benefits.

The proposed tracking solution is aimed to be a wireless system that employs technologies of both the 4^{th} and 5^{th} generations of wireless communications, offering improved flexibility, setup simplicity and high performance.

1.3 Purpose of 5G in Asset Tracking

Over the past years, the Industry 4.0 initiative escalated the rapid increase in production efficiency, promoted the creation of new business opportunities, and enabled high data rate wireless connectivity in high volume manufacturing settings. Factory automation represents a principal industrial area targeted as part of this engineering movement, with typical applications such as real time control and monitoring of assets to stimulate fast production rates and improve product or service quality.

Traditionally, factory automation is employed in discrete manufacturing, where processes consist of many discrete operations and steps. Thus, in-time messages or commands are key to minimise delays in the production flow. Consequently, network stability and fast response times (i.e. low latency) are of essence for those applications, and implicitly, for the present use case that is required to provide real time asset location.

For material out-life monitoring, it is also critical to have representative data of the product location, as if not correctly detected by the sensors, the updated material work life could potentially be incorrect (i.e. asset reported as stored in the freezer while being physically stored at room temperature, leading to unrepresentative work life information). Therefore, a 5G network would provide improved reliability and stability of the wireless connection, minimising the likelihood of missing a tagged asset.

Another network requirement for asset tracking is the ability to connect many devices to the network without compromising its connectivity or stability. The proposed asset tracking solution relies on RFID gates being deployed in stations representative of an AFP workflow that offer information on asset location. Deploying the existing infrastructure further into the NCC factory floor requires more sensors to be installed in the production environment – sensors that are connected and send data over the same network.

Furthermore, in the NCC production environment, numerous radio frequency interference sources were identified on the factory floor (i.e. high voltage power supplies, large metal structures). Those were found to act in the same frequency spectrum as the NCC private

4G network, causing large packet losses and latencies in a number of stations that in turn greatly affected the end user experience (e.g. delayed or incorrect asset location update). It was believed that a 5G connection would move the frequency bandwidth higher in the spectrum – from 1.8 GHz (where both the 4G LTE network and the recorded electromagnetic interferences were acting) to 5 GHz (5G network). Thus, the interferences would be avoided, and a robust connection would be provided to the system.

The ability to wirelessly monitor location and life of assets in a production environment, combined with increased network reliability, device connection capabilities and low latency are 5G characteristics that would enable a real time asset tracking experience for this use case. These network characteristics were also the use case requirements employed in measuring the success of the asset tracking test bed.

2. Overview

2.1 Use Case Architecture

An asset tracking solution was designed and deployed within the NCC factory floor and encompasses key features, typical of an AFP process. The system comprises both software and hardware elements and focuses on tracking time-sensitive materials, tooling and finished components, using 4G and 5G private networks, as well as RFID technologies. The engineering concept behind the proposed solution relies on a static system – several RFID gates are strategically positioned in areas representative for an AFP process.

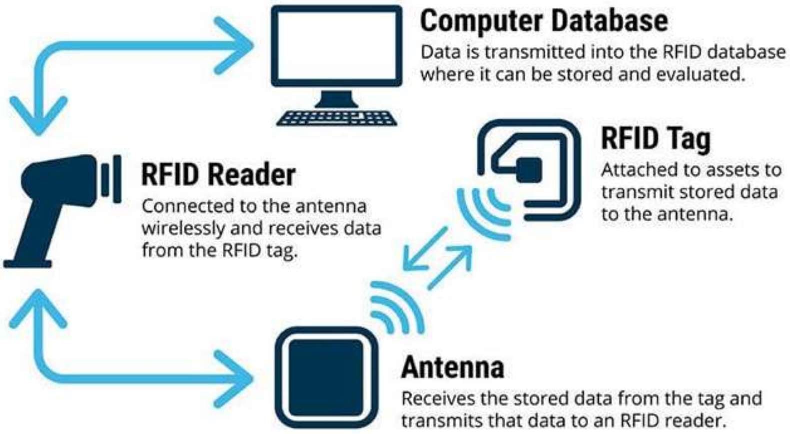


Figure 2 System architecture diagram [1]

As the tagged asset moves between workstations, passing the RFID gates, the RFID tag is detected by the antenna and the asset location is automatically updated in the live web asset tracking application offered by Plataine (i.e. Plataine TPO). A key system functionality is the end user ability to access goods information and monitor assets remotely, on edge devices by simply connecting to the web application (Figure 3).

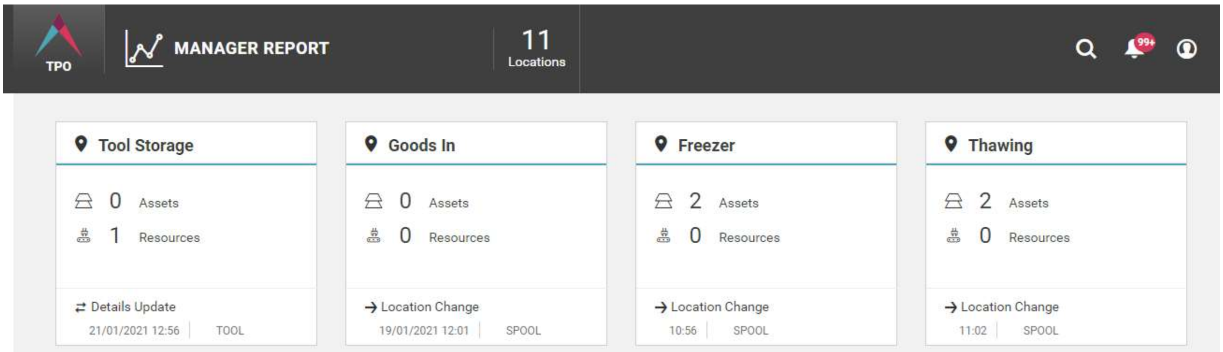


Figure 3 Plataine TPO user interface

The solution presents the ability to effectively track mobile tools and assets in real time, as well as remotely monitor time-sensitive composite material characteristics, such as composite shelf or work life. Also, the Plataine TPO environment offers users the great benefit of storing asset information and manufacturing documentation (i.e. manufacturing reports, NDT scans), providing a live database of all active assets on the shopfloor.

The asset tracking solution (i.e. Plataine TPO) is independently communicating asset information (e.g. material stock and availability, tool readiness and maintenance requirements) to the employed manufacturing execution system (MES), Siemens Opcentre. Each manufacturing activity is translated in a set of operations and steps, which are then released in Opcentre in the form of a work order.

Depending on the material availability and existing stock, spools of material are assigned to the work order and the manufacturing information is captured in the form of a report. Ultimately, a digital passport of both AFP prepreg materials and associated products is generated in TPO, containing manufacturing and post-processing information.

The RFID gateways were installed in seven distinct locations around the NCC factory (Figure 3) that would follow the manufacturing process flow (Freezer – Thawing – AFP Coriolis robot – Autoclave – NDT – Metrology – Tool storage in Figure 4). Thus, the zonal location of each asset can be closely monitored throughout the entire production process.

Each gateway consists of two RFID antennas directly connected to an RFID reader via a co-axial cable, which in turn is connected to a 4G and, respectively, 5G router, or uses a POE connection. Table 1 summarises the network connections found in each shopfloor area.

Workstation	Network connection
Freezer	4G (wireless)
Thawing	5G (wireless)
AFP Coriolis cell	4G (wireless)
Autoclave	Wired POE
Non-destructive testing (NDT)	4G (wireless)
Metrology	4G (wireless)
Goods In & Tool storage	Wired POE

Table 1 Available network connections

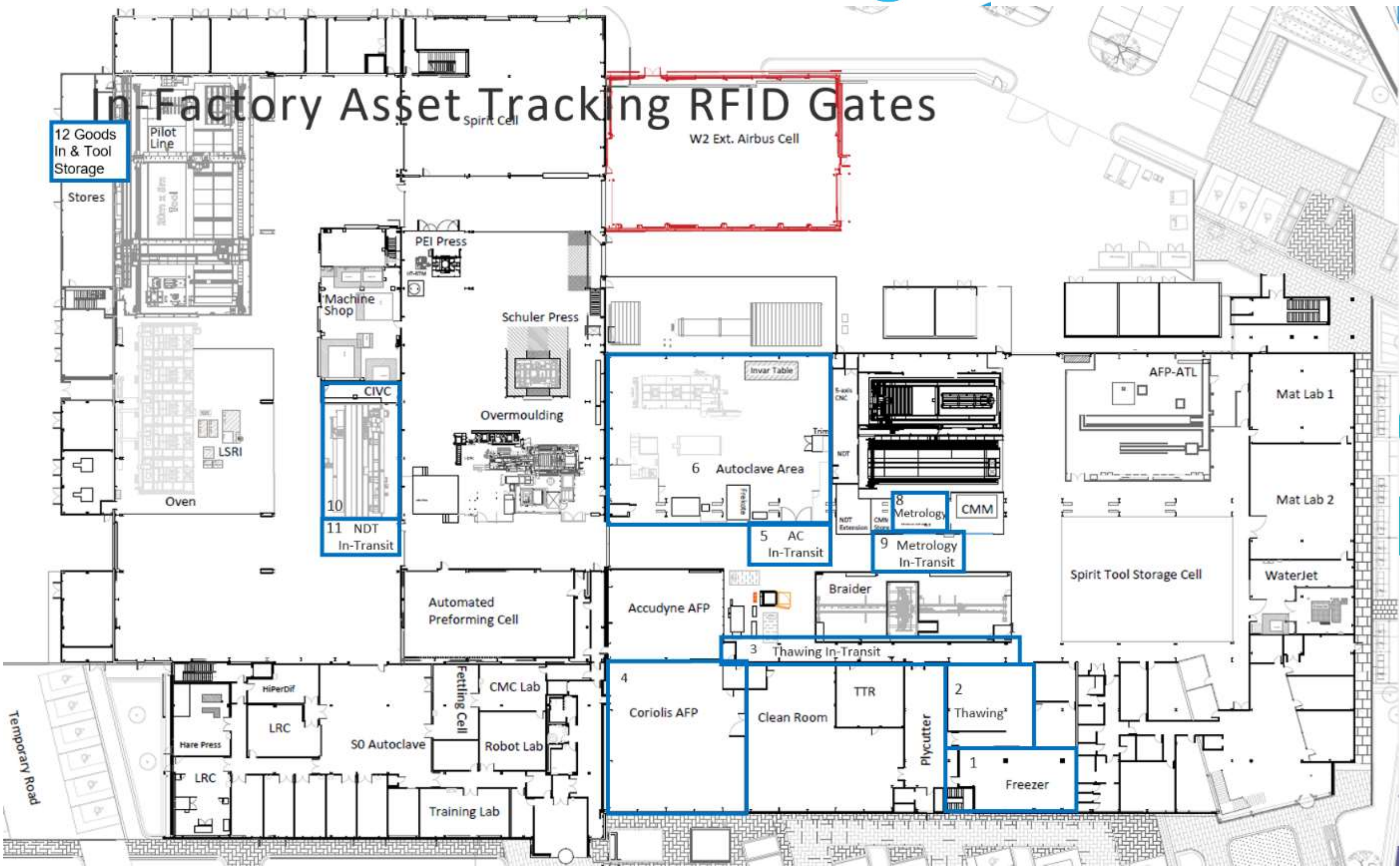


Figure 4 RFID gateways placement in workshop stations

2.2 Use Case Metrics

Network stability, latency and packet loss

The asset tracking solution relies on a static sensor system as the RFID gates indicate the zonal location of the assets on the factory floor. Thus, network stability was key for this application to ensure continuous connectivity of the system to the network and a robust data update. Considering the manufacturing environment the RFID gates are located in, there is an increased chance in electromagnetic interference (i.e. presence of high voltage supply units, large metal structures). Thus, it was of essence for this use case that these existing interferences did not alter the network signal, speeds or packet loss.

Key for this application were both latency and packet loss as those could greatly impact the real time update of asset location in the web application (e.g. the asset location update was not captured due to data being lost or it was not representative of its real location– slow response). Thus, it was desired within the use case that 0% packet loss was achieved, as well as low latency. However, these network performance metrics proved to be greatly affected by electromagnetic interferences, as experienced with a 4G connection.

5G also offered minimal latency and improved upload speeds (up to 57 Mb/s) that could facilitate the quick update of the tagged asset location in the web application. For this use case, a maximum latency of 10ms was required, easily achieved with a 5G network connection. Therefore, compared to the 4G baseline, a 5G network was believed to considerably improve the user experience when using the asset tracking test bed, offering accurate real time information on the asset location and its properties, as well as supporting future real-time optimisation studies for production planning.

Improved capacity to handle vast amounts of data wirelessly

In a production facility, the number of tools, materials and cured components (i.e. assets) could vary considerably depending on production capabilities. The larger the production facility or manufacturing rate, the larger the number of assets to monitor. 5G offered the great advantage of managing great amounts of data, while accommodating a larger number of end devices within the Internet of Things to connect, without compromising network stability, latency or speeds.

Thus, a reliable real time asset tracking system had to manage a large number of RFID gates, as well as a considerable amount of data traffic as numerous assets updated their location continuously on the factory floor. Consequently, as 5G could address this system requirement, it became of interest to assess its implicit capabilities.

2.3 Development Journey

The aim of the project was to provide the end users with a reliable real time asset tracking solution that could provide accurate and representative data on the item location and availability, as well as time sensitive information, such as product out-life or tool maintenance requirements. It was key for the use case to enable an interactive and user-friendly system interface where the asset condition and location could be remotely monitored on handled edge devices. Thus, three sub-systems were identified to enable the desired asset tracking capabilities:

- RFID hardware acting as gates between stations.
- An asset tracking web application (i.e. user interface).
- An MES solution.

The current industrial applications for asset tracking solutions rely extensively on RFID technologies. Thus, it was of interest to deploy an RFID gateway system on the factory floor that would autonomously communicate information on asset location to a live web application where the data could be accessed remotely – Plataine TPO.

Plataine, a world-leading provider of intelligent automation and optimisation software solutions for advanced manufacturing, was identified as a valuable partner for this use case based on their experience with smart asset tracking applications based on RFID technologies.

As an IoT and AI-based optimisation solution (i.e. Plataine TPO) was employed as the asset tracking web application, it was decided to also integrate an MES (Siemens Opcentre) as part of the proposed system architecture and create a fully digitalised AFP manufacturing ecosystem. Nowadays, the MES solution represents the backbone of automated manufacturing processes, as it generates and captures most essential manufacturing data.

As Plataine and Siemens had previously tested this autonomous data sharing between the two systems, it was of interest for the use case to understand how an automatic data transfer of manufacturing information from Opcentre to TPO could be integrated in a high value manufacturing production. This communication represented a mean to minimise the number of manual inputs required from the operator or engineer and capture all asset information in a centralised live environment (i.e. TPO recording asset location, material information – expiration date, out-life and stock –, tooling maintenance, manufacturing data).

Thus, the 5G-Encode AT use case aimed to integrate these three independent sub-systems in a single industrial application that provides full asset traceability information, from material and tooling data to key manufacturing details. The real time AT capabilities were then unlocked by deploying a 5G network connection on the factory floor (i.e. RFID data transferred from the shop to the TPO server via a 5G network).

3 Use Case Development and Investigation

3.1 Use Case Development

The use case team developed an asset tracking solution comprising of both software and hardware components. Their functionality and testing completed are detailed in the following sections.

3.1.1 In-factory Asset Tracking Testbed

A system network architecture was designed and implemented in the NCC factory floor, following an AFP process flow and utilising wired and both 4G and 5G network connections, as well as RFID technologies (Figure 5).

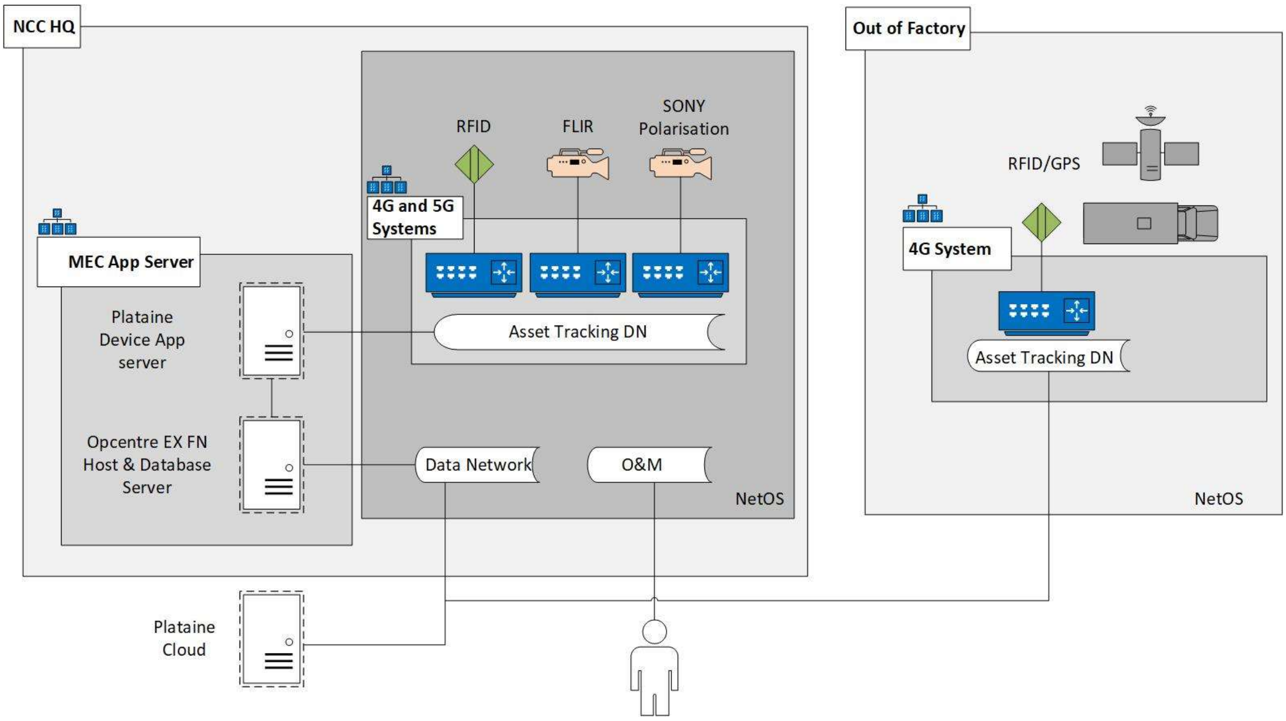


Figure 5 Asset tracking network architecture

An initial 4G solution was developed within the NCC shopfloor to act as a baseline. Originally, six 4G small cells operating on a 5 MHz bandwidth were placed in the NCC factory to provide coverage to the use cases within the 5G-ENCODE project. RFID gateways were installed in seven distinct locations representative of an AFP process flow, so that the zonal location of each asset could be remotely monitored using the asset tracking user interface provided by Plataine.

The RFID sensors make an IP connection to the Plataine device-app server deployed on the project network, updating the asset location as it passes by each gateway. An example of an RFID gate and implicit hardware components can be pictured in Figure 6.

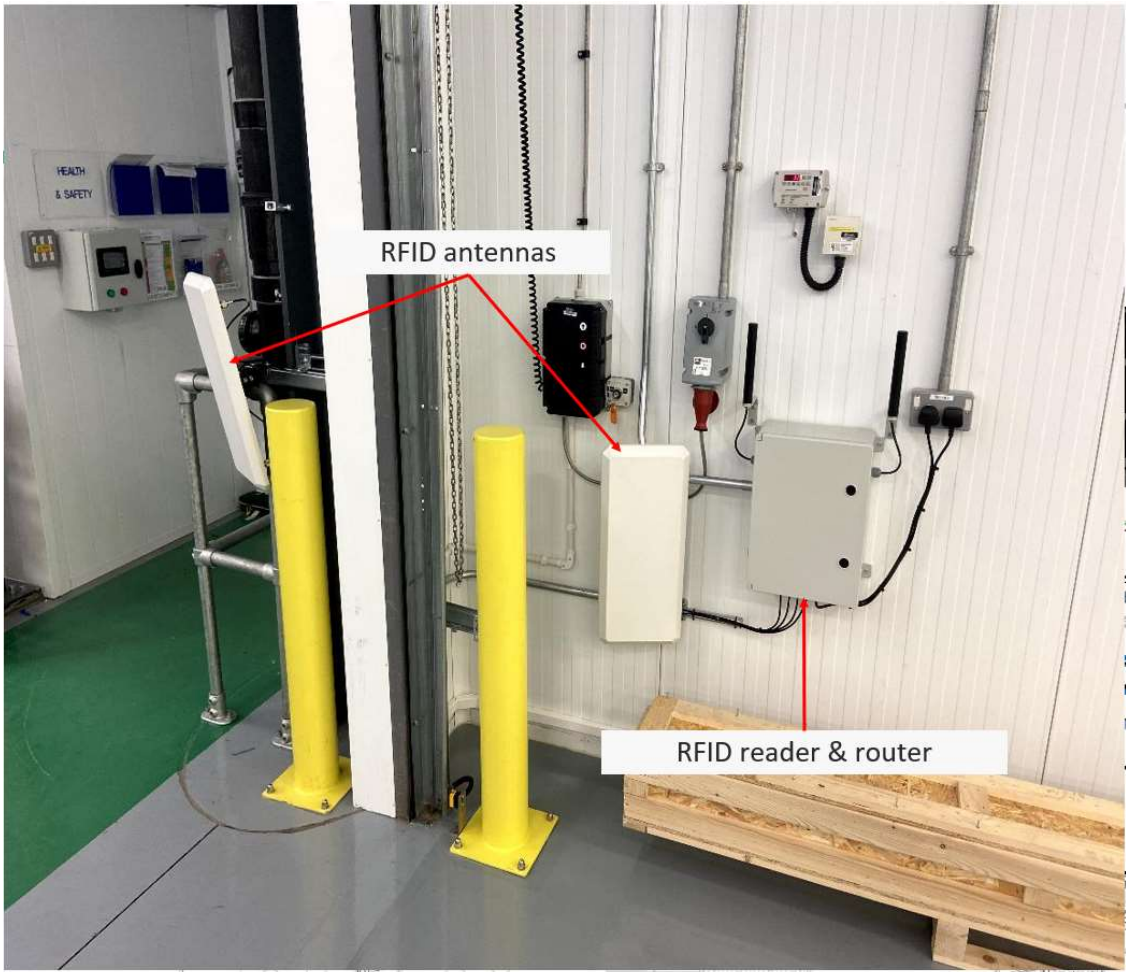


Figure 6 RFID gate in the AFP Coriolis cell

An RFID gate consists of two main components as identified in Figure 6:

- An electronics box consisting in a Zebra FX7500 RFID reader, a Siemens Scalance M876-4 4G router and two Siemens SINAUT ANT-794-4MR antennas to pick up the 4G signal.
- One or two Laird wide band circular polarity RFID antennas.

The RFID antennas are connected directly to the RFID reader via a co-axial cable, which is connected to the 4G router via an RJ45 (i.e. ethernet) cable. The 4G router sends and receives data over the NCC private 4G network and communicates directly with the use case server. This solution allows for the data sent over the 4G network to be viewed and managed on edge devices remotely.

Five of the stations were originally connected to the 4G network, while the remaining two (i.e. Autoclave, Tool storage), utilise a wired POE connection. This was due to the existing concerns over the 4G signal strength in those areas.

For the 5G test bed, the same system architecture was employed as for the 4G baseline, mimicking the exact same process flow. The main difference consists in having a 5G network connection in one of the cells (i.e. 'Thawing' station), with the rest of the RFID gates being connected to 4G. A Robustel 5G router (Figure 7) was installed in the respective cell, with the RFID reader connected to the Robustel unit via an ethernet cable.

Figure 7 Robustel router setup in the 'Thawing' station

No other stations were upgraded to a 5G connection due to unavailability of resources (e.g. reduced number of available NCC IT engineers and 5G routers, short installation window prior to the deployment of the upgraded test bed).

Furthermore, each individual cell is modelled in Plataine TPO as shown in Figures 8 and 9, offering information on the material, tooling and preforms existing in each respective area. For instance, for a spool of material, by accessing the asset entry, it is possible to view information on the material utilisation and out-life.

This information is automatically shared with the MES solution (i.e. Siemens Opcentre) once a production run is scheduled. The manufacturing data, along with an update of the available material stock are then autonomously shared by Opcentre with TPO at the end of manufacturing. Thus, the number of manual operations executed by the operators in capturing this type of data is reduced. Further information on the autonomous systems communication between Opcentre and TPO is provided in Appendix B.

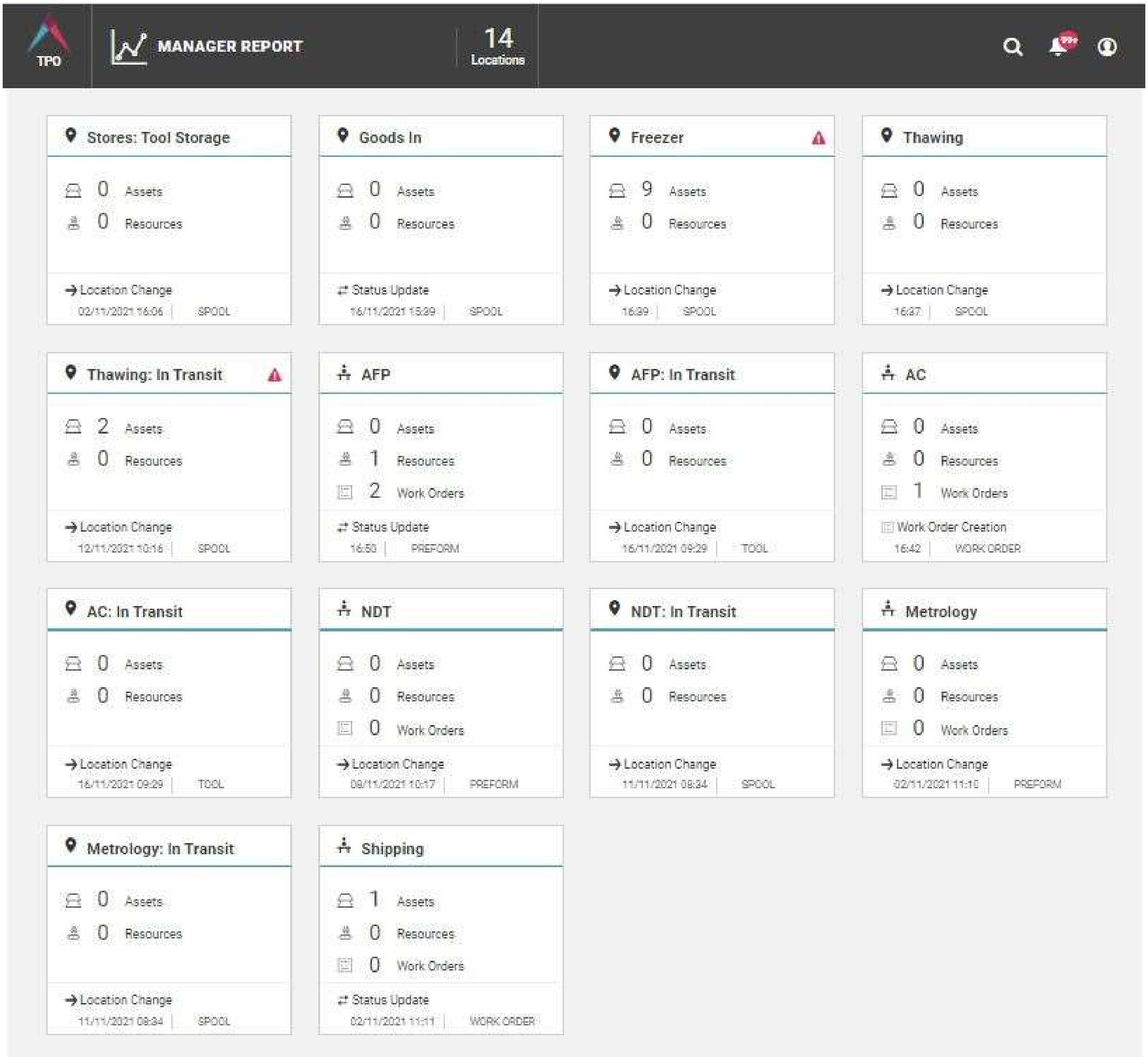


Figure 8 Plataine TPO – Visualisation of AFP stations

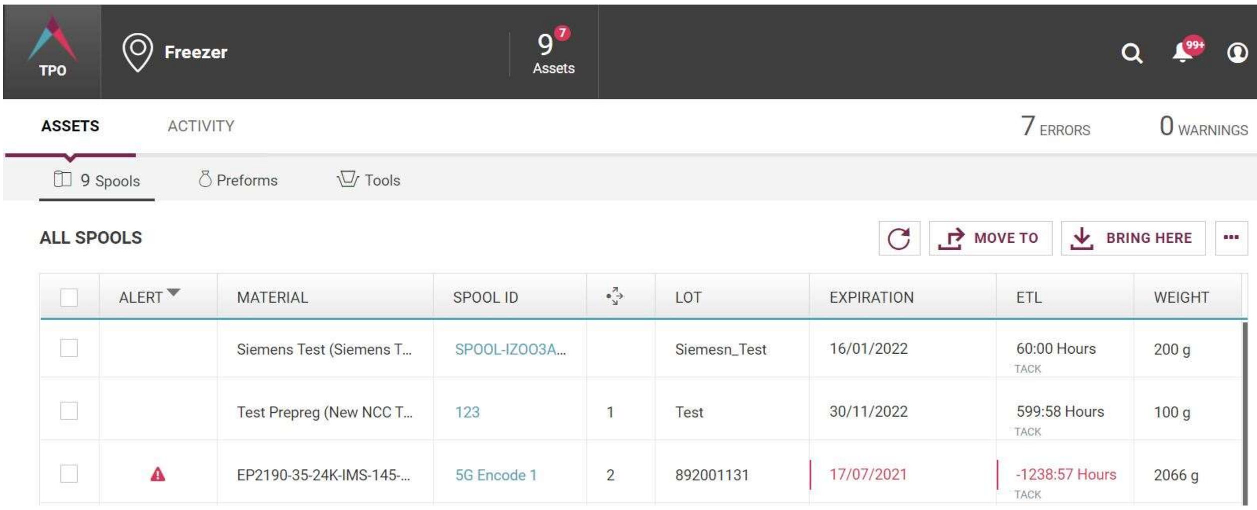


Figure 9 Plataine TPO – Defined asset entries

In order for the assets to be tracked on the factory floor, each item is tagged with a unique RFID label. The tags are printed using a Zebra (ZD500R) passive RFID printer that is connected via a CAT6a port to the same network as the asset tracking system, to enable full system functionality. An example of the RFID tags used in the use case is shown in Figure 10. For tooling, the assets are tagged using high-temperature resistant RFID labels as those experience numerous curing cycles at elevated temperatures.

Figure 10 Example of asset RFID tag

3.1.5 Out-of-factory Asset Tracking

One of the requirements for this use case was to enable out-of-factory tracking of temperature sensitive materials. An automatic solution for in-transit data sharing between Solvay (i.e. the supplier) and the NCC (i.e. the customer) was sought to closely monitor material out-life during delivery between the two sites (Solvay facilities in Wrexham to NCC headquarters in Bristol Emersons Green).

Figure 12 shows the different operations the spools of material undergo from delivery to producing a final cured component.

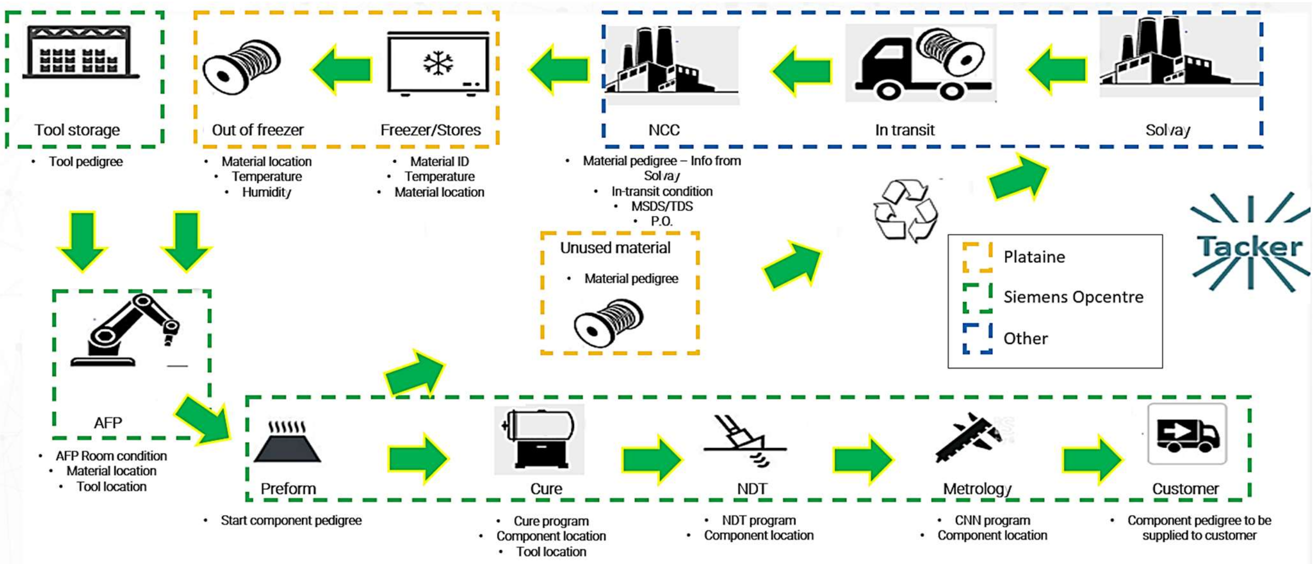


Figure 11 End-to-end material monitoring – from supplier to production

Originally, a 5G solution was desired; however, due to limited coverage of the public 5G network, a 4G out-of-factory solution was trialled. Two options have been considered:

- Utilise Solvay's in-transit sensor technology (Sensitech) as an LTE solution to track asset location via 4G and GPS while monitoring environmental conditions.
- Tether an RFID sensor to a dual sim 4G / 5G device and track the asset into the transit, user GPS data to track the device while in-transit and transition to the NCC private network when in range.

Solvay's decision was to monitor the product out-life when in-transit using Sensitech sensor technology as the required solution infrastructure was readily available and easy to integrate as part of a handover process with the NCC.

The information was to be captured automatically in Plataine TPO once the material arrived on site, with the asset having already been created in the web-application. However, due to the increased cost of the proposed solution, an alternative process was implemented. This alternative solution consists in the material manufacturing information to be supplied by Solvay to the NCC once the material is released for delivery. This information is captured in an EXCEL CSV template that can then be easily imported into Plataine TPO and generate the asset entries.

In-transit data (i.e. temperature readings and GPS location) are continuously recorded during transportation by Solvay using their Sensitech sensors. To preserve material properties and out-life, the products are stored directly in the freezer while processing the delivery at the NCC. If any material out-life is lost in transit, this information will be provided by Solvay and captured in Plataine TPO.

3.2 Use Case Testing

When assessing the use case test bed performance, two types of tests were considered:

- Application tests (evaluating the performance of the asset tracking system from the user's perspective and identifying areas of improvement for the proposed solution).
- Network tests (relating the performance issues derived from the application test to representative network performance metrics and evaluating those against the network requirements).

When enabling the independent system communication between Opcentre and TPO, further testing was required. These tests were completed in the form of dry runs by creating and scheduling a number of work orders and assessing the means by which data is exchanged between the two systems. In this section, the application tests and implicit findings are detailed.

3.2.1 Application Testing

The application tests consisted in following the process flow and record any system performance issues that were negatively impacting the user experience. The main aim during an application test was to validate that the RFID hardware (i.e. reader and respective antennas) was enabled at each one of the seven stations and that the tagged asset location was updated in Plataine TPO as the asset moved between stations.

Once the material entries were generated in Plataine by importing the Excel CSV spool template, the respective RFID tags were printed and attached to the product packaging. As the work order was scheduled and the material was moved to the 'Pick list' in TPO, the spools were withdrawn from the freezer and placed on the acclimatisation rack. For the material to be assigned to a work order in Opcentre, the spools of prepreg tape had to be located in the 'Freezer' station. The RFID gate would detect the tagged material and the 'Defrost' timer would start. In the meantime, the time the material spent outside the freezer was recorded and subtracted from the material work life.

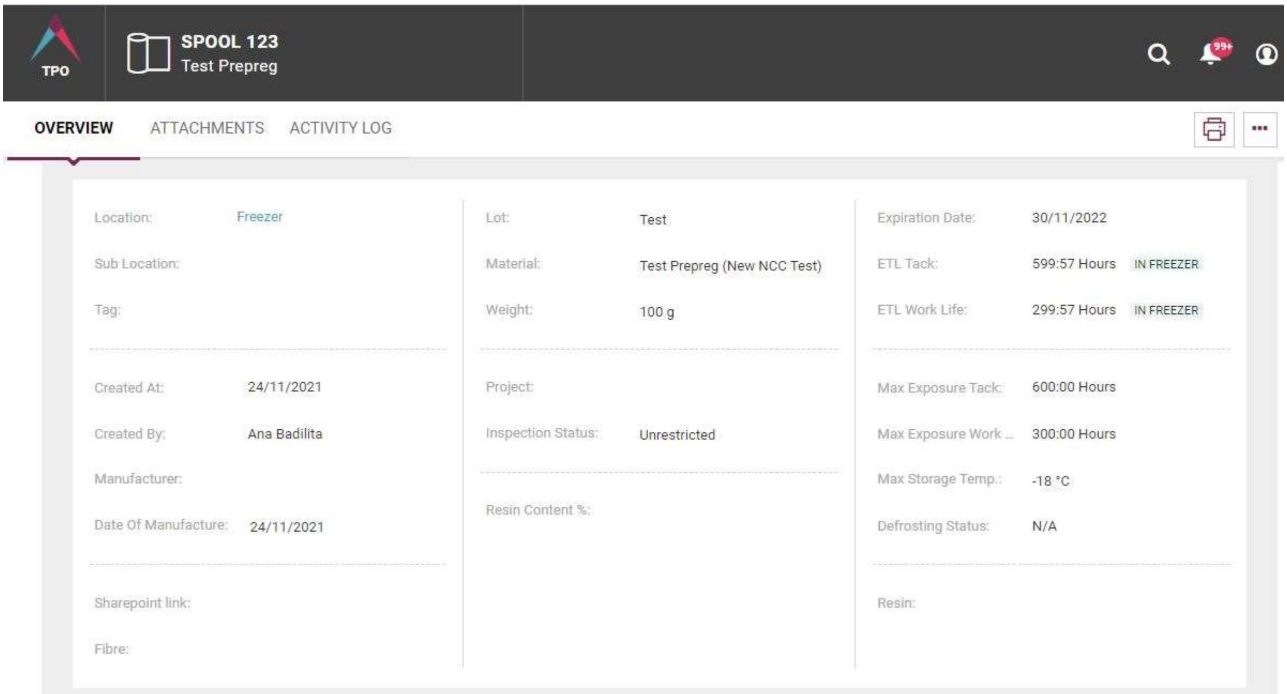


Figure 12 Material shelf and work lives captured in TPO

When the material was fully defrosted, the work order was executed on the AFP Coriolis robot and a new preform entry was created in Plataine. Curing and post-processing reports were attached to the newly created asset entry once each operation was completed. For each created preform, information on the material batches, tooling and manufacturing were captured in Plataine. At the end of the manufacturing operations (i.e. production of the uncured preform), the spools of material were weighed, and the available stock quantities were updated in Plataine TPO as the composite material was returned to the freezer. For simplicity, right corner preforms were created on the AFP robot and closely monitored during the manufacturing stage.

Each asset was tracked around the shopfloor while the location update was monitored in the Plataine web application. For the goods to be easily detected by the RFID stations, the tags had to be partially visible to the antennas. Thus, placing the tags on the outer product packaging and ensuring a direct line of sight with the RFID gate was agreed as the best practice to facilitate asset detection.

For the 4G baseline, in certain areas, such as the 'Thawing' station and the AFP Coriolis cell, the material detection was delayed; thus, it was necessary for the spools to be carefully manipulated in the proximity of the gate for the antennas to detect the RFID tags. After further calibration work was completed on the antennas, it has been decided that the delay in updating the material location in TPO was a network issue rather than a hardware one. Consequently, it was of interest to assess the network performance with a series of network tests. These are detailed in section '4.1.1 4G LTE Testing and Outcomes'.

Overall, the test bed showed great potential for a robust real time asset tracking solution, but further work was required to understand how the network performance influences the user experience and, implicitly, the test bed performance.

3.3 Use Case Discussion

3.3.1 Limitations of Use Case

The proposed asset tracking solution has proved to be an effective mean to monitor both the location of tagged assets, but also the material work and shelf lives. However, the existing system was configured for a single linear production flow and was tested using a relatively small number of assets.

When considering a high-volume manufacturing environment, the number of assets that are to be tracked is considerably larger compared to the one used to develop and evaluate the proposed asset tracking test bed. A future requirement created as a result of this project is to assess how large amounts of data are managed and updated in the web application using the current system architecture.

A 5G connection would facilitate a larger number of end devices (i.e. RFID gates) to be connected to the network and also easily cope with larger amount of data being uploaded to the server relatively quickly; thus, offering a real time asset tracking experience for a representative production environment. Also, this would allow a large number of RFID gates (i.e. stations) to be connecting to the network and, therefore, facilitate a better coverage in big warehouse spaces or manufacturing settings. These 5G capabilities are of interest to assess in future trials and tests.

Another limitation of the proposed use case is that the RFID gates only indicate zonal location of the asset. The system architecture was deployed within the NCC factory floor, targeting a number of cells that are representative of an AFP process. Those cells are relatively small and facilitate identifying the correct asset quickly and efficiently if the zonal location of the good or material is already known. If we are to consider larger manufacturing areas or production lines, either at the NCC or other similar production environments, the proposed system might not be as efficient in aiding users to easily identify the exact location of the asset.

For an automatic mean to closely monitor tools or materials, it is of great importance to minimise the manual input required from the end user. This is why an alternative mean to communicate part or material information was considered. However, this type of autonomous system communication was only enabled between the MES solution and TPO.

For future work on the asset tracking solution, it would be of great importance to integrate automatic means of data sharing with the TPO web application, similarly as for Siemens Opcentre. For instance, it would be beneficial to enable TPO to independently communicate with other pieces of software or systems used at the NCC (e.g. Polyworks software tools used by the metrology team). The current procedure solely relies on communicating the metrology reports via email and manually attaching it to the preform entry in TPO, causing potential delays in releasing the information online or accidently skipping this final step.

3.3.2 Siemens Opcentre and Plataine TPO Communication

The Siemens Opcentre and Plataine TPO communication was meant to enable an automatic and independent material and manufacturing data exchange between the two systems. Once the work order is created, scheduled and started in Siemens Opcentre, certain commands would be enabled to closely monitor the available material stock. These commands include a stock update with the new available quantity on the spool after manufacturing is completed or a request for additional material if necessary.

With the NCC factory floor being the first manufacturing environment this communication was enabled in; a number of issues were encountered. However, the communication was enabled successfully, and it is now possible to extract material information from Plataine TPO when scheduling a work order in Siemens Opcentre.

A number of issues had to be addressed prior to testing this communication; some of those blockers included:

- A Siemens software update to configure the composite material class in Opcentre that delayed configuring this system feature.
- Differences in date and units of measurement formats between the two systems that prevented a correct information exchange (Figure 14).
- Incorrect links created between Opcentre and TPO to access the material information and update its stock.

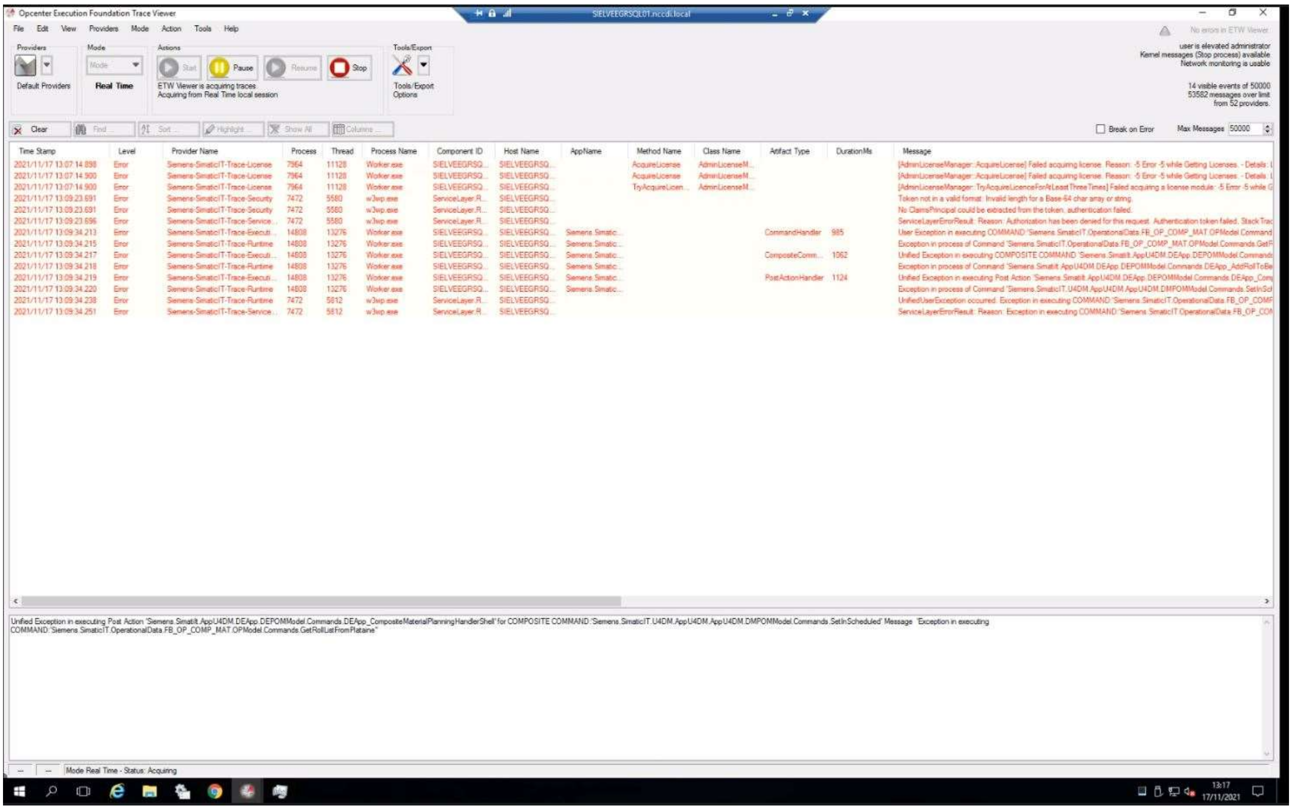


Figure 13 Errors caused by time and date format issues in Siemens Execution Foundation Trace Viewer

While those have been addressed successfully, a number of tasks are still pending:

- Enabling more than one material entry to be linked to a work order in Opcentre.
- Configuring additional commands

- To update existing stock information in TPO based on the material quantities consumed during manufacturing.
- To request and assign additional stock from TPO during an operation in Opcentre.
- To attach a part manufacturing report from Opcentre to the respective preform entry in TPO.

These features will be tested prior to project closure.

3.3.3 Lessons Learnt

Flexibility of asset tracking solution

For this particular use case, the asset tracking solution was demoed for one specific manufacturing process – an automated fibre placement process. The existing system was configured for a linear production flow, using a relatively small number of assets and covering only seven work cells in the NCC factory: Freezer – Thawing – AFP Coriolis cell – Autoclave – NDT – Metrology – Tool storage. However, the technologies and web solution employed by the use case proved to be easily adapted and customised for any manufacturing environment or process.

RFID gate calibration

When deploying the RFID gates in the NCC factory floor, the calibration of the antennas was a critical operation to ensure the functionality of the asset tracking solution. Based on the performance of the RFID gates over the past year, it is believed that periodic recalibration of the hardware is required. It would also be of interest to explore remote means to calibrate the RFID antennas, as the current procedure is mostly manual and highly tedious. This involves an operator to define the coverage area of the antennas around each gate manually using an RFID tag, being a time-consuming trial-and-error process.

Collaboration and cross-team knowledge sharing

For this use case, the engagement of zone owners, technical authorities and technicians was of great importance to integrate an asset tracking test bed in the factory floor workstations. This enabled the use case team to identify potential industrial challenges that could have been resolved by the proposed asset tracking solution. For instance, by enabling the manufacturing execution system to update material stock and automatically provide part manufacturing data to Plataine TPO, the number of manual steps that are usually completed by the technical authorities or project managers were drastically reduced. It also improved time efficiency as tasks were not delayed and they were completed instantaneously as the work order was completed in Opcentre.

Re-use by other organisations in the Enterprise

There is a strong business interest in deploying the asset tracking solution in the rest of the NCC factory. The findings of this use case showed great potential and benefits for composite manufacturing, attracting the interest of several teams and business units.

Automation of data transfer

As one of the use case requirements was to enable out-of-factory tracking of composite materials, an automatic solution for in-transit data sharing between Solvay and the NCC was sought. The existing solution relies on the manual transfer of material information between the two parties, which is then imported in Plataine TPO. However, Plataine is currently exploring solutions to address this use case limitation by implementing a new feature in their web solution that could potentially facilitate automatic data sharing between Solvay and the NCC.

Expanded use to organisations outside the Enterprise

As the NCC is a research and development centre for composite materials, it would be valuable to expand this solution to other suppliers, as well as customers. This way, the existing infrastructure for out-of-factory asset tracking will continue to develop and facilitate easy access of small to medium size businesses to this technology.

3.4 Use Case Benefits

3.4.1 Business Value Propositions

The key performance indicators value drivers for asset tracking were identified and summarised below:

- Productivity improvement – time resources saved on unproductive tool location searches.

- Sustainability – improved material stock management solution (i.e. minimal material wastage).
- Cost savings – reduction of costs associated with outdated material disposal.
- Cost savings – reduction of costs associated with damaged tooling requiring attention or rework (i.e. improved monitoring of tool maintenance requirements).
- Tool and equipment control – close monitoring of tool utilisation and its maintenance schedule (i.e. number of production cycles a tool has seen).

These performance indicators were used to assess and quantify the benefits of the proposed asset tracking solution in a production environment.

3.4.2 Use Case Benefits

<u>Provide accurate and real time location of assets</u>

Lack of tool storage or inconsistent work practices in a production environment can lead to tools becoming more susceptible to loss or damage, especially if stored inadequately. In turn, this will cause difficulties to future users to easily locate the assets when required. Consequently, a significant amount of time resources is wasted searching for and locating tools, which can lead to further losses of time and cost to the business.

The key benefit of this asset tracking use case is to efficiently track mobile assets in real time to minimise the current unproductive time spent searching for those items.

Based off the experience of the NCC, a productivity improvement of up to 5% in time is seen per standard 7h manufacturing jobs when the asset tracking system is employed; this is measured by booked hours against predicted hours for specific tasks. Consequently, time savings in the production environment directly minimises the business costs of manufacturing as productivity is increased and the resources – operator / machine time – are efficiently used in the shopfloor.

Monitor key assets and provide better selection of material for the application based on material work / shelf life

Composite materials have a limited shelf and work life, requiring special storage conditions (e.g. -18 °C) to preserve their high-performance characteristics. Once the material reaches its expiry date the, the remaining stock is typically disposed as its mechanical properties degrade, resulting in waste.

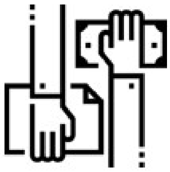
Plataine TPO allows users to search for existing material stock (i.e. consume first available stock prior to placing a new material order) and facilitates a better approximation of future orders based on similar production runs (i.e. minimising risk of overspent either due to overestimating quantities or a need for additional spools of prepreg). The asset tracking solutions enable project managers to better forecast project spending based on similar productions and offers better control over stock with estimated savings between £56,000 and £200,000 in raw material every year.

Monitor key assets and allow for better selection of tooling

Monitoring tooling maintenance and ensuring its appropriate storage is key for guaranteeing the quality of tools and, implicitly, the performance of the final cured component. In addition, if tool utilisation and maintenance are not accurately recorded, costly quality issues to the final product may be caused.

Plataine TPO captures key tool information along with its current location. Thus, it is possible to monitor its use, predict future maintenance work and ensure its appropriate storage. Based off the experiences at the NCC, an annual savings of up to £200,000 were estimated, accounting for cost savings of tooling repurchase or rework due to either loss or damage.

Reduce bureaucracy



Excessive bureaucracy elimination

The existing solution at the NCC relies extensively on tracing information on paper or storing it in multiple locations to ensure its traceability. Time-sensitive information and stock quantities are captured manually, while materials are assigned to work orders and production runs via an internal request form that is also manually filled and processed.

The proposed asset tracking solution independently communicates with the MES solution offered by Siemens, enabling an automatic data sharing process between the two systems. The material is linked automatically and uniquely to a work order and, once the product is removed from the freezer, its remaining out-life is closely monitored.

Based off the experiences of using the asset tracking system at the NCC, a time saving of 47 min per work order was recorded, which, implicitly, resulted in a £46 saving per job. Considering the average number of jobs that are scheduled in the NCC per year, the total cost saving is of £63,000, while requiring only 13% of the original time (i.e. manually recording material out-life, requesting materials).

3.5 Use Case Conclusions

An asset tracking and monitoring solution such as the one proposed by the present use case could potentially have an outstanding impact on the cost and quality of production for any manufacturing facility, using, or intending to use large numbers of assets. A key benefit of the proposed solution is also the ability to automatically monitor product work life for assets that possess time sensitive properties, leading to savings up to £200,000 a year in stock.

Also, another key benefit is the system’s capability of recording asset availability, either in the form of stock quantities for consumables or maintenance requirements for tooling. The Plataine TPO system allows to keep a record of the material stock based on its weight and it can be automatically updated via the Siemens Opcentre and TPO communication channel.

This can lead to a better understanding of a facility's stock management practices, while tooling usage and maintenance monitoring can lead to an improvement in quality by driving down the number of non-conformances resulting from improperly maintained tools (e.g. savings of up to £200,000 pounds per year for tooling reconditioning).

Also, the number of manual steps required from the end user is small, taking only 13% of the original time to request material stock, update its weight post-manufacturing and record part manufacturing data. This considerably improves the efficiency of the process and minimises human error (e.g. manually recording material out-life).

The proposed test bed shows to be an adequate mean to communicate RFID data around a production shopfloor; and, while there are a number of tasks to be completed to improve the robustness of the existing system, the proposed solution appears to have great potential for a reliable real time asset tracking solution. In the short term, there are a number of pending activities to be completed to improve system reliability. These include testing a 5G connection in the 'AFP' station to reduce the likelihood of the reader to disconnect from the system and enabling the communication between the MES solution and TPO.

4. 5G industrial Assessment

4.1 4G LTE and 5G Network Testing

A number of tests were carried out within the NCC factory to ensure that each RFID station was connected to the Encode network either via 4G, 5G or POE. At the time of writing, the 'Tool Storage' station was not online as an additional switch was required to connect the gate to the Encode network. Thus, the gate was not included in any of the testing below.

For both 4G and 5G, the network performance was evaluated by simply executing a ping test in the 'Command Prompt' window to determine the latency and packet loss experienced at that port. Also, during the application tests, the network is monitored to assess its performance during the entire manufacturing process.

Two major testing periods were delivered:

- January 2021 – evaluating the performance of the 4G testbed (formally referred to as 4G testing).
- November 2021 – assessing the network performance of the testbed with the 5G router installed in the 'Thawing' station and the upgraded 4G network (often described as 5G testing).

These consisted of running an application test in parallel with a network diagnostic and link the test bed performance to the respective network metrics.

4.1.1 4G LTE Testing and Outcomes

For the 4G baseline, each station was pinged 50 times and the packet loss and latency were measured. The results are shown in Table 1.

Station	Packet Loss (%)	Min Ping (ms)	Max Ping (ms)	Average Ping (ms)	4G Signal (dBm)
Freezer	0	22	470	81	-62
Thawing	6	21	105	79	-70
AFP Coriolis	8	22	541	84	-59
Autoclave	0	0	0	0	N/A
NDT	0	25	113	66	-62
Metrology	0	22	217	73	-49

Table 2 4G RFID Stations – Ping test data

The average ping measurements were found to be less than 100 ms for every station, which for this application, it was considered of adequate value. However, the maximum ping values were alarmingly large in some of the areas, including the ‘Freezer’ station and the AFP Coriolis cell. These were deemed as outliers from the average; however, the asset tracking solution at the time still performed relatively poorly in the ‘Freezer’, ‘Thawing’ and ‘AFP’ stations from the end user’s perspective. These issues were detailed in section 4.1.2 ‘4G Test Bed Limitations’.

Further investigations were conducted at the time in those cells. The signal strength was monitored for 100 seconds to investigate both the consistency and the magnitude of the signal in each station. The recorded values in decibel-milliwatts (dBm) are also summarised in Table 1. As a general rule, a value greater than -73 dBm indicated a satisfactory signal strength. As all seven stations recorded values above the lower limit, it was concluded that the 4G Siemens routers were an adequate mean of communicating data between the asset detection hardware and the server.

Looking into the packet loss measurements from January 2021, it was thought that those could be a result of potentially poor signal strength or electromagnetic interferences. For the ‘AFP’ station, the signal strength was one of the highest observed among the seven different cells and it was concluded that interference was a more likely cause for the poor network performance in the area (e.g. high voltage supply unit powering the AFP robot, a roller door isolator switch located in the proximity of the RFID gate). As previously mentioned, the packet loss appeared to affect the Plataine asset management system, leading to the RFID gate becoming not operational.

Similarly for the ‘Freezer’ and ‘Thawing’ stations, there were a number of interference sources in these areas, including high voltage power lines, an IT server room and numerous large metallic structures located next to the stations. In all three areas, the interference was occurring in the lower frequency spectrum (1.8 – 2 GHz), affecting the 4G network.

It was thought that by changing the bandwidth frequency (i.e. upgrading to a 5G connection that acts in the higher frequency spectrum) the network performance could be improved. Another hypothesis was that the stations were subject to shadowing effects caused by the presence of obstacles that were obstructing the signal from the 4G cell to the RFID gate.

A network upgrade was successfully completed and an improvement in the packet loss and response times was observed (4% – maximum packet loss in the 'AFP' station and 2% - maximum packet loss in the 'Thawing' area). The minimal packet loss that was still seen in the AFP cell did not appear to greatly impact the tracking as the asset location was updated in real time and all tags were correctly detected by the gates. However, as the testbed performance in the 'Acclimatisation' station was still highly unsatisfactory.

Further network performance metrics on the upgraded 4G LTE network were provided as part of an application test conducted in July 2021. The network performance was monitored for the entire test period, between 09:00 AM and 11:30 AM on the day. The recorded metrics are provided in the graphs below.

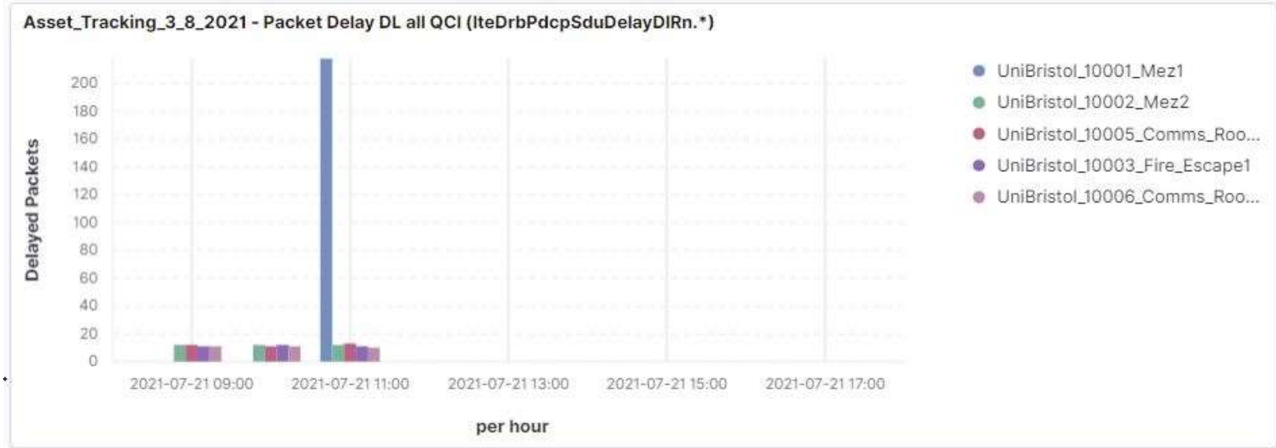


Figure 14 Packet Delay (Latency)

Regarding the latency results (Figure 15), the measurements indicate consistent average values of 10 to 13 ms across all cells, with the exception of one, where values of up to 210 ms were recorded. The extreme values seen in this cell ('Thawing' station – UniBristol_10001_Mez1 in the plot legend)) were believed to be caused either by poor coverage from the network cell or interference in the 4G bandwidth. For the rest of the cells, the recorded latency values were deemed as satisfactory.

Comparing these values with the network metrics previously recorded during the January tests, an improvement in latency could be seen in most areas, exception being the 'Thawing' station. This consolidated the team's decision to deploy a 5G network connection in this particular station on the factory floor.

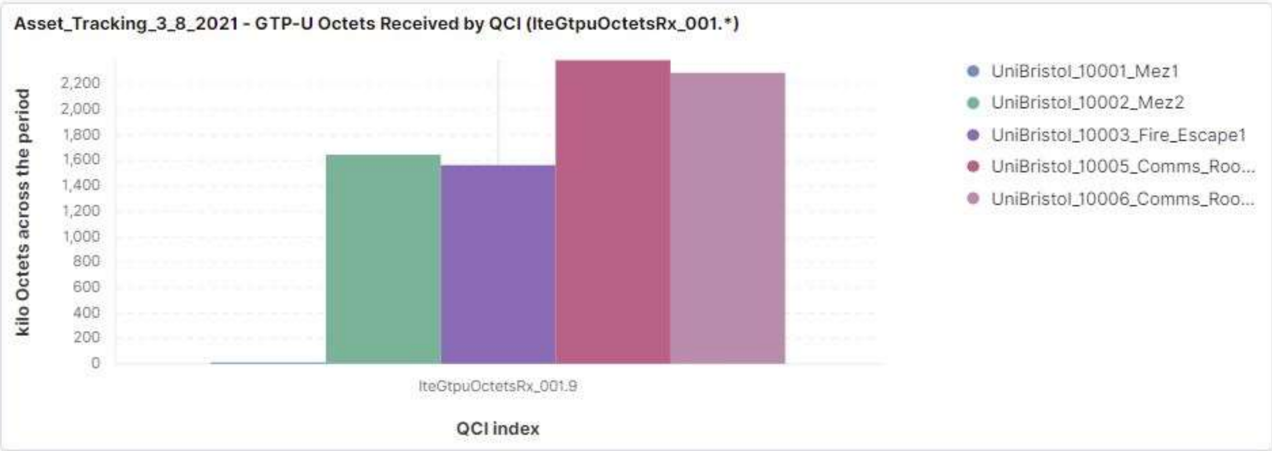


Figure 15 Downlink Throughput

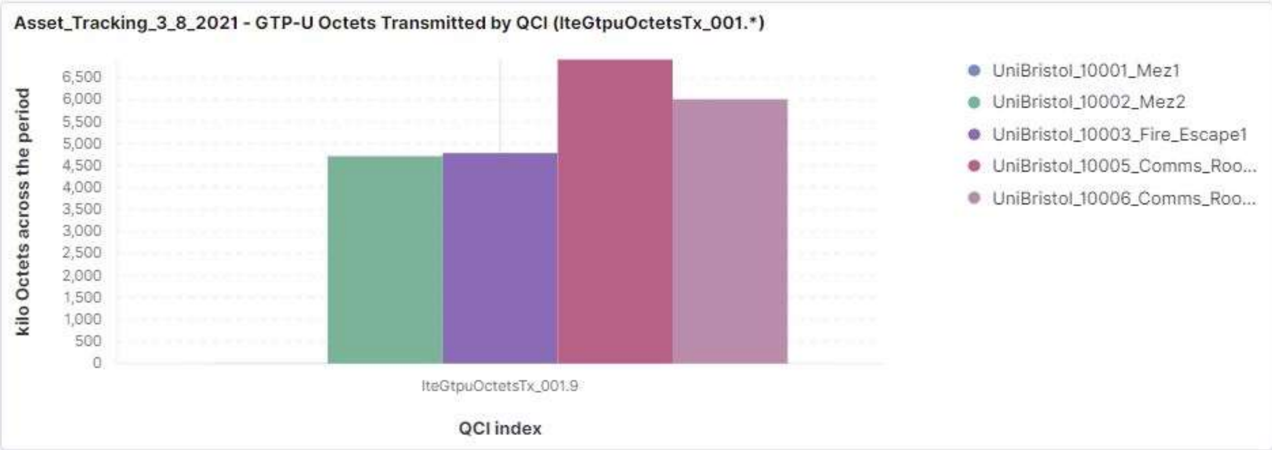


Figure 16 Uplink Throughput

The traffic generated by the RFID tags was also monitored for both uplink and downlink. The recorded values in the shopfloor areas are shown in Figures 16 and 17. Peak traffic values of 380Kb (downlink) and 80Kb (uplink) or above were considered as satisfactory. Thus, based on the recorded data, the results were deemed as acceptable.

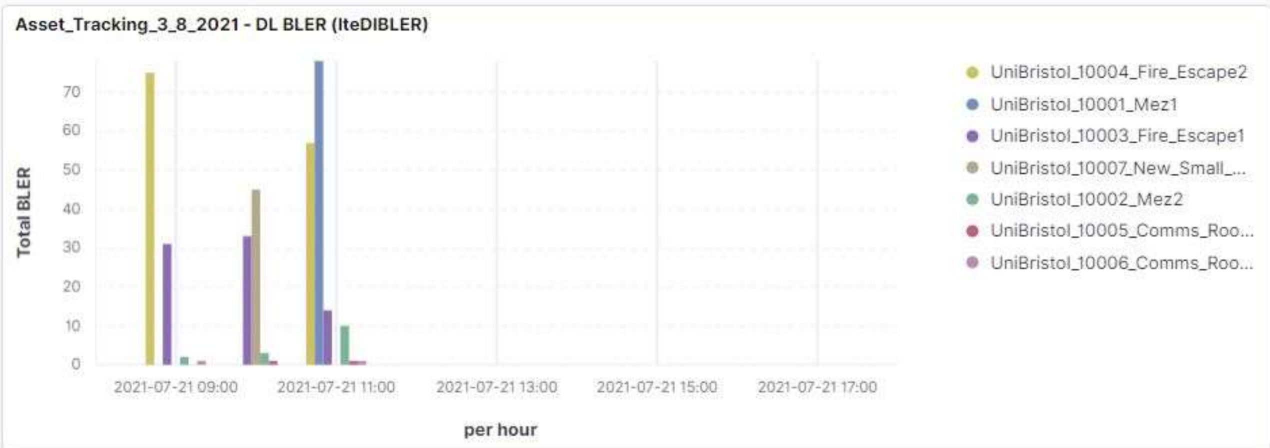


Figure 17 Block Error Rate – Downlink

Figure 18 Block Error Rate – Uplink

The block error rate – BLER – (Figures 18 and 19) was also recorded as part of the 4G network test. The metric is defined as the ratio between the number of received erroneous packets of data to the total number of transmitted packets, reflecting on the RF channel condition as well as on the level of interference experienced by the system.

Values between 2 to 5% are considered satisfactory for a 4G wireless connection; thus, for some of the cells, the high BLER results represented a concern. The causes of the poor block error rate performance seen in some of the areas were still unclear at the time, but it was believed these were related to either poor network coverage in some of the cells or the presence of interference.

No packet loss was seen throughout the test period.

Due to the poor network performance recorded in the 'Thawing' area, also proved by the additional network metrics measurements, it was decided for the cell to be upgraded to a 5G connection. It is important to understand that with a 4G cellular connection the likelihood of encountering a certain level of packet loss is higher than for a wired POE connection. However, as the recorded values in the 'AFP' station were meeting the requirements for a wireless connection, these packet loss values were deemed acceptable.

4.1.2 4G Test Bed Limitations

The 4G test bed presented a number of performance issues that were directly linked to 4G network limitations. Increased packet loss and latency represented a concern in two main areas, ‘Thawing’ and the AFP Coriolis cell. A detailed description of the tests carried, and their respective results are captured in section ‘4. 5G Industrial Assessment’.

The poor network performance directly affected the test bed performance. One of the main challenges was capturing all instances of the asset moving between stations due to packet loss. In the case of time sensitive assets, for instance uncured composite materials, missing the instance the material moved in or out of the freezer could have meant that the recorded time the product spent at room temperature was not accurately captured.

Another issue was the delayed location update in the web application as the asset moved passed an RFID gate. In this case, the location of the asset was not representative of its physical location, making the system less reliable and accurate.

Also, the recorded packet loss did appear to affect the Plataine asset management system, as well as the connection consistency of the reader to the 4G network. The web application is configured to notify the user if any packet loss is recorded by sending a notification in the user interface. Then, the reader is rebooted, and the network connection is established again. However, it was often required to reboot the reader manually by switching it off and on, as the RFID gate would not be operational.

The cause for the unsatisfactory network performance was down to be the presence of electromagnetic interferences in these two areas. The main sources of interference were identified as the high voltage supply unit that provided power to the AFP robot in the Coriolis cell, as well as large structure cells and the NCC’s uninterrupted power supply for the IT server room located in the ‘Thawing’ and ‘Freezer’ areas.

A network upgrade was completed and enabled a more stable 4G connection, and also an improved user experience when using the test bed. This upgrade consisted in increasing the 4G frequency bandwidth from 5MHz to 20MHz. Some minimal packet loss could still be observed in the AFP Coriolis cell; however, as these values were within the tolerance requirement for a wireless network, it was not a concern for this use case.

The signal strength and implicitly the slow response times recorded in the ‘Thawing’ area still paused some issues (i.e. slow location update of the assets in Plataine TPO resulting in a less representative real time asset tracking solution). Thus, as the use case had only one available 5G router, it has been decided to upgrade the network connection in the 'Thawing' area to a 5G one.

4.1.3 5G Testing and Outcomes

Similarly to the 4G tests, the 'Thawing' station was pinged 50 times and the packet loss and latency were measured. The 4G network connection in the rest of the cells was also monitored. These network metrics tests were performed regularly over a period of three weeks and the average values were summarised in Table 2.

Station	Packet Loss (%)	Min Ping (ms)	Max Ping (ms)	Average Ping (ms)
Freezer	0	26	113	69
Thawing*	0	11	41	26
AFP Coriolis	2	25	114	70
Autoclave	0	0	0	0
NDT	0	25	114	66
Metrology	0	23	115	72

Table 3 Upgraded 4G and 5G RFID Stations – Ping test data

* Thawing area was upgraded to a 5G network. All other areas remained connected to a 4G network (i.e. wireless or POE connections).

The end user experience in the 'Thawing' station was drastically improved after the upgrade to a 5G network connection. No packet loss was experienced over the 3-week monitoring period. The response times were also considerably improved with values as low as 11 ms. These metrics corresponded to a better asset tracking experience consisting in faster updates in the web application and high system reliability in monitoring tagged assets. It appears the 5G connection in this station addressed all performance issues that were causing great inconveniences for the end user when engaging with the test bed.

A correct asset location update was considered crucial for this use case. If any RFID gates had not successfully detected a moving asset between stations, its location would not have been correctly updated in the user interface. This would have led to delays in identifying the correct location of the item and, for time sensitive products, if not correctly detected by the antennas, their remaining out-life would have not been captured accurately.
Thus, the improvements brought to the network improved the test bed performance.

4.1.4 5G Pre-requisites for Use Case Application

The 5G network capabilities at the NCC are summarised in Table 3.

Network Metric	Metric Value
Latency	< 10 ms
Uplink speed	Approx. 57 Mb/s
Packet loss	0 %

Table 4 U5G Use Case Requirements

Looking at the network metrics values recorded as part of the 5G testing, the average latency was 26 ms, with a minimal value recorded of 11 ms. The uplink speed was also recorded as varying between 5 to 24Mb/s, with 0% packet loss recorded throughout the 3-week monitoring period. Even though, these values are below the expected 5G network performance capabilities, from an end user experience, the data transfer is fast and representative of the live location of the asset. 0 % packet loss also minimises the likelihood of missing a tagged asset as it passes an RFID gate. Thus, the reliability of the system in detecting the asset and updating its location is improved.

It can be concluded that, with the current 5G network, all interference and performance issues recorded on the 4G test bed have been addressed and the recorded network metrics values were satisfactory to meet use case requirements. It would be of interest to assess the impact of a 5G connection on the test bed performance in the 'AFP' station.

4.2 5G Discussion

4.2.1 Benefits of 5G

5G wireless systems are expected to be enablers for factories of the future, addressing the existing limitations of the 4G LTE technologies. Higher speeds, lower latencies and the capability of connecting many end devices without affecting network connectivity and stability are just a few of the improvements proposed by the fifth-generation mobile network. Those are also key network requirements for our use case.

Compared to a 4G connection, 5G offers reduced latency and higher upload speeds (up to 57 Mb/s in the uplink) that facilitates the quick update of the asset location once detected by the RFID gate. For this use case, a maximum latency of up to 10 ms is required, easily achieved with a 5G network connection. Therefore, compared to the 4G baseline, the 5G network considerably improved the user experience when using the asset tracking test bed, offering accurate real time information on the asset location (i.e. 11 ms latency).

As highlighted in a previous section ('5G Testing and Outcomes'), the user experience in the area upgraded to a 5G connection was drastically improved after the network upgrade. No packet loss was recorded over the 3-week monitoring period, improving network reliability in the area.

Another major benefit of 5G is its capability to allow many end devices to connect simultaneously to the network. In a production facility where multiple RFID gates might be required to cover large manufacturing units, 5G can provide a reliable connection to a high number of smart devices, without compromising its performance (i.e. speeds, latency, connectivity). Also, larger data transfers can be managed on a 5G connection, allowing to easily track a large number of assets.

As proved by this use case, 5G also removed the main sources of interference, otherwise specific to a production environment, by moving the bandwidth frequency higher in the spectrum. Based on the original assumptions, the poor network behaviour was related to the existing signal to noise interference in the cell.

4.2.2 Limitations of 5G

Capacity

The 5G connection at the NCC proved to be reliable and address all performance issues identified on a 4G connection. However, the use case employed a minimal number of assets to be tracked and only one RFID gate connected to 5G. It would be of interest to assess the capabilities of 5G by deploying the connection in other stations on the factory floor, while tracking a larger number of assets.

Device availability

5G is still a relatively new technology, with a limited number of devices available on the market (i.e. 5G CPE routers or 5G enabled sensors), which made testing of business cases particularly challenging. As the 5G standalone technology evolves, it is expected that the range of smart devices compatible with a 5G connection will expand as well.

IT skills and knowledge

Having a strong knowledge and understanding of networks proved crucial as well to ensure that both the 4G and 5G network deployed within the NCC were robust and functional. Also, enterprise IT departments are usually not accustomed to dealing with cellular technology and the implicit requirements; thus, promoting a continuous information exchange across the industry would enable a faster development of infrastructure and technology, while minimising the implicit costs of deploying 5G.

5G network performance

For a 5G network, the download speeds are considerably higher compared to the upload speeds (e.g. 400 Mb/s downlink speed, 57 Mb/s in the uplink – NCC capabilities). However, the upload speeds achieved within this use case appeared satisfactory for a real time asset tracking solution. But as the number of connected end devices scales up, there could be capacity limitations that need to be accounted for.

4.3 5G Conclusions

An asset tracking solution as proposed by this use case could potentially bring great financial and quality assurance benefits to any manufacturing setting, such as a reduction of approx. 93% in asset search time, boosting productivity and minimising time waste, while closely monitoring material out-life, which ensures the final component performance.

The 5G network connection did prove to considerably improve the test bed performance and bring a better and more representative real time asset tracking experience to the end user compared to the 4G baseline.

As the 5G network is less sensitive to RF interferences, a more robust and stable connection was provided to the 5G asset tracking test bed, enabling real time updates of item locations in the user interface and minimising packet loss (i.e. robustness in correctly detecting the assets and recording their location). 5G proved to be a reliable solution in the 3.6 GHz to 3.8 GHz frequency range; moving away from the various interferences seen at specific locations as described above.

In production environments where the number of RFID gates and tracked assets is considerably high, the data upload can be easily completed via a 5G connection without compromising the network performance (i.e. connectivity, speeds, latency). Based on the recorded network metrics, a 5G connection provides fast response times (down to 11 ms), 0 packet loss and upload speeds of up to 24 Mb/s that drastically improved the overall performance of the test bed. However, those were recorded while handling a relatively small number of mobile assets. It would be of great interest to assess if, for a larger number of assets, the same network metrics are recorded.

The proposed solution is not perfect and further work is required to assess the potential of 5G in asset tracking. However, compared to the 4G baseline, 5G proved to be an efficient mean to communicate RFID data around a production environment, placing the foundations of a potentially ground-breaking cellular technology asset tracking solution.

References

[1] *Smartt Tag Ltd Rfid Solutions*. SmarTT Tag Ltd RFID solutions. (n.d.). Retrieved December 9, 2021, from http://smartt-tags.com/.

Appendix A – Data Captured as Part of the Manufacturing Passport

- Material Passport: Information related to the material – In-Transit data:
  - In transit shipment date
  - Material code/lot/type references
  - Quantity
  - Weight
  - Date of manufacture
  - Storage condition
  - Shelf/out of life

- Material Passport: Information related to the material – In-Factory data:
  - Arrival date from supplier
  - Storage location
  - Storage condition
  - Material movements
  - Maximum exposure work time
  - Maximum exposure tack time

- Preform Passport: Information related to the cured composite part – Manufacturing and inspection data:
  - Manufacturing information
  - Date of manufacture.
  - Manufacturing method
  - Process key parameters.
  - Equipment and tooling
  - Curing information
  - Date of curing.
  - Cure data sheet
  - Process key parameters.
  - Equipment and tooling

- Inspection information
  - NDT and metrology requirements.
  - NDT and metrology report

- Key Process parameters.
- Equipment and tooling

Appendix B – Siemens OC and Plataine TPO Interaction

The asset tracking solution proposed by this use case consists of two systems: a manufacturing execution system (MES) – Siemens Opcentre – and an asset tracking web application – Plataine TPO. To minimise the number of steps that technicians, engineers or other technical authorities are required to complete and the manual input of data (e.g. recording material out-life, requesting material stock), it was desired for the two systems to independently exchange asset information.

The first step is to generate a sequence of operations representative for the process flow that is to be followed, for instance the AFP process. These operations have to be linked to work areas or units, as well as to a sequence of steps describing each action to be completed in the operation. Figure 19 shows a number of operations and their implicit relations for an AFP process.

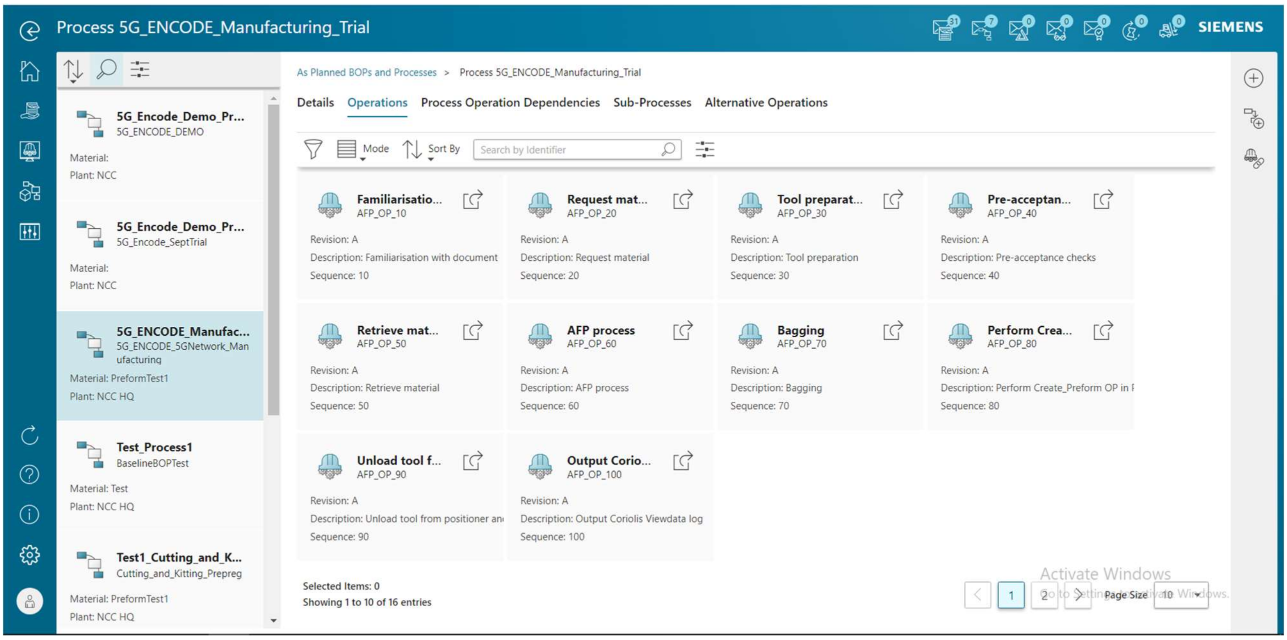


Figure 19 Operations sequence created in Siemens Opcentre for an AFP process

At the step level, it is of great importance to specify the material that is to be consumed and its quantity, for instance the number of plies of prepreg, in order to link the material managed by TPO to the work order created in Opcentre, as presented in Figure 20.

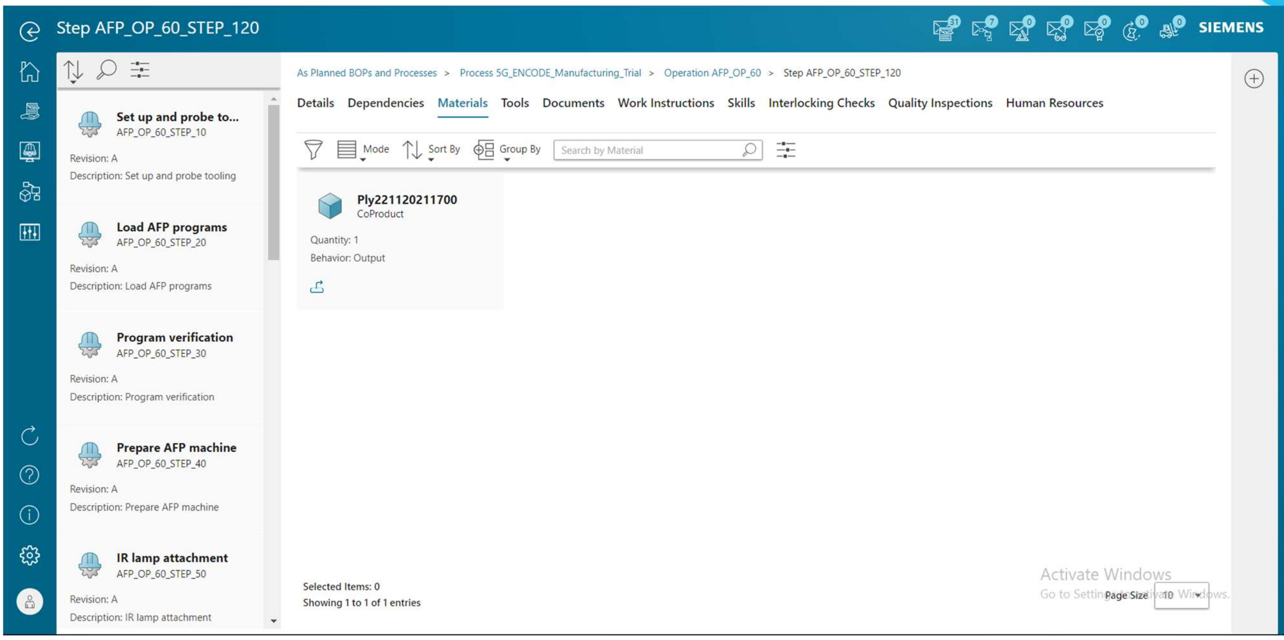


Figure 20 Step and material relation in Siemens Opcentre

The material product is to be stored in the Opcentre materials catalogue as a composite and be attributed a 'CompositeMaterialINId'; an example of a material entry in Opcentre is offered in Figure 21. This 'CompositeMaterialINId' is the material name associated to the spools of AFP tape, for instance, in Plataine TPO.

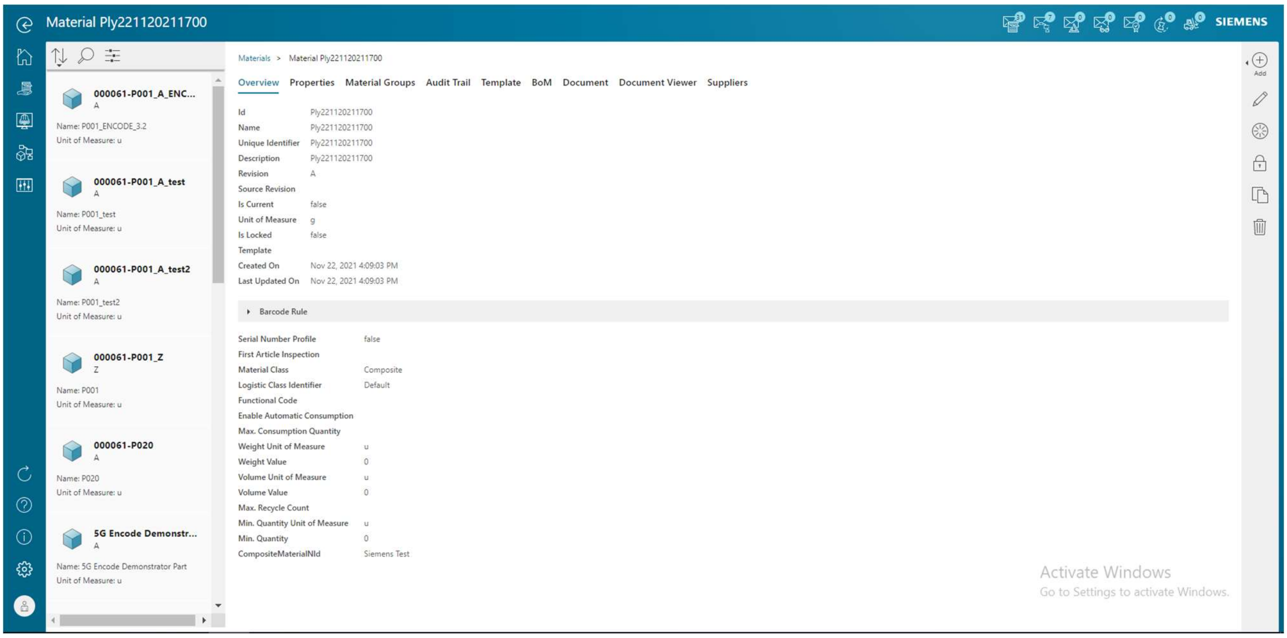


Figure 21 Material entry in the Opcentre 'Materials' catalogue

Once the process is released and a new work order is generated from this process, the sequence of operations can now be scheduled in APS (Siemens software for scheduling Opcentre work orders). The user interface of the scheduling tool is captured in Figure 22.

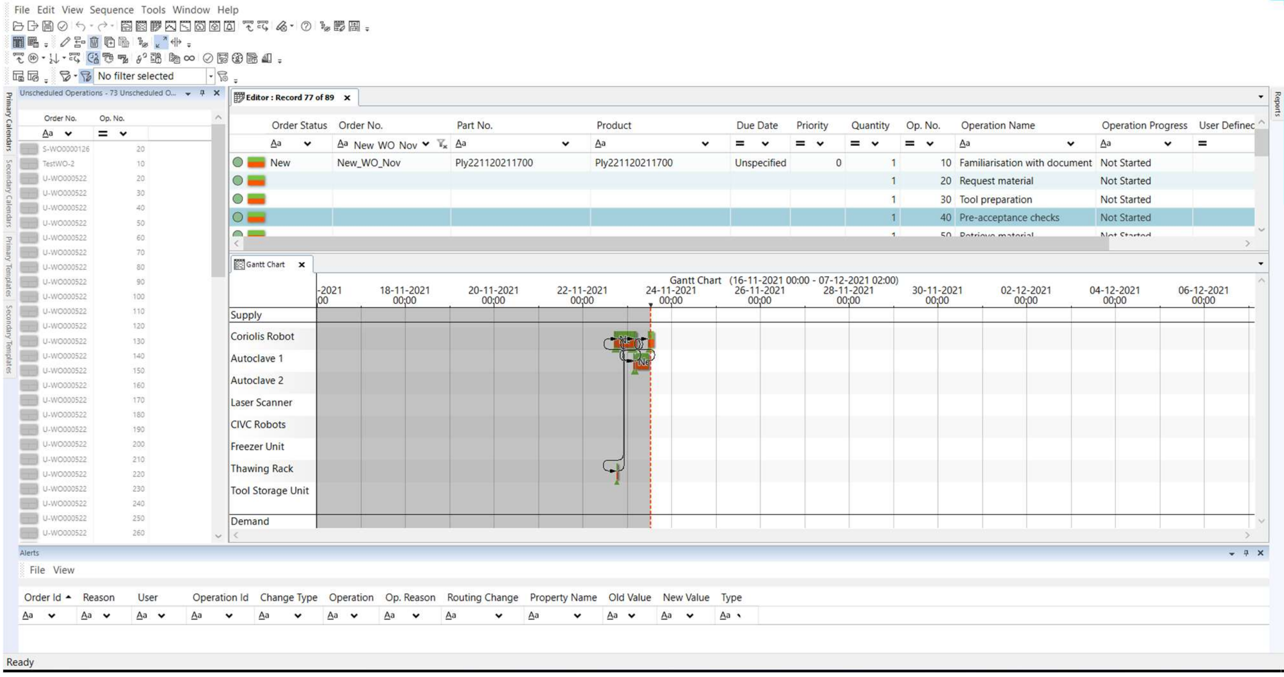


Figure 22 Siemens APS user interface

At this stage, the spools of material in Plataine, depending on the available stock, are associated to the respective step in Siemens Opcentre. Once the material is linked to a process, the spools of prepreg are moved to a ‘Pick list’ environment in TPO (Figure 23) to prevent the material from being assigned to multiple work orders simultaneously.

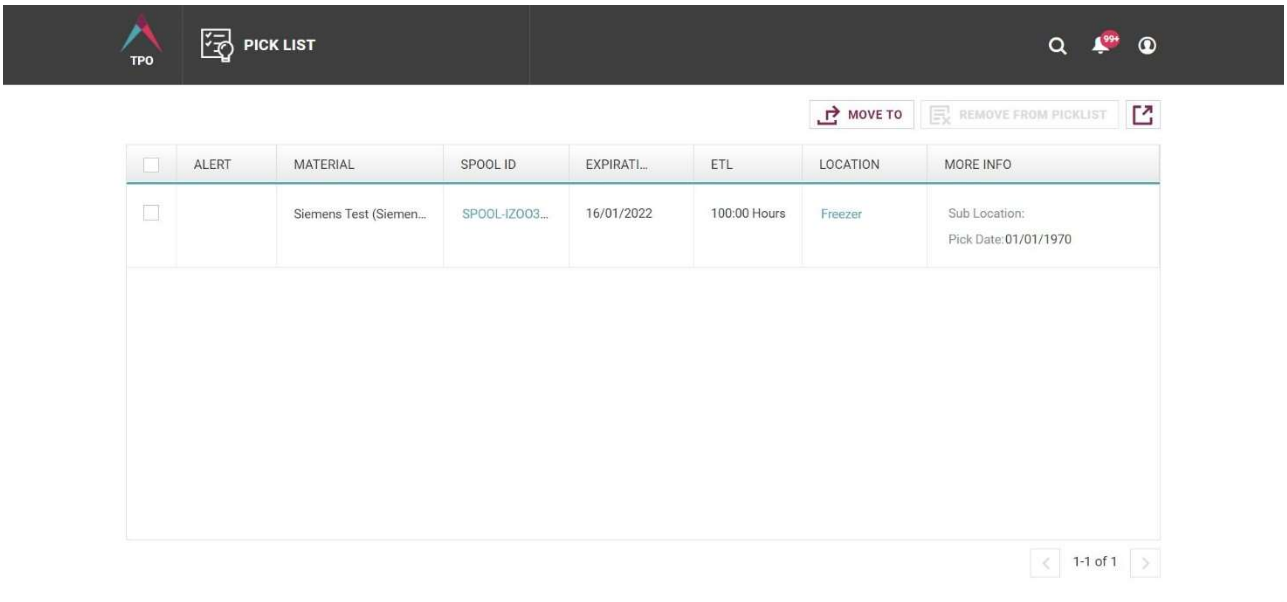


Figure 23 Plataine TPO ‘Pick List’

In the ‘Operator Landing’ environment, where operations are signed off by the technicians or other technical authorities, it is possible to review the material information captured in TPO, including batch ID, available stock, as well as shelf-life or data. The operator user interface in Opcentre is captured in Figure 24.

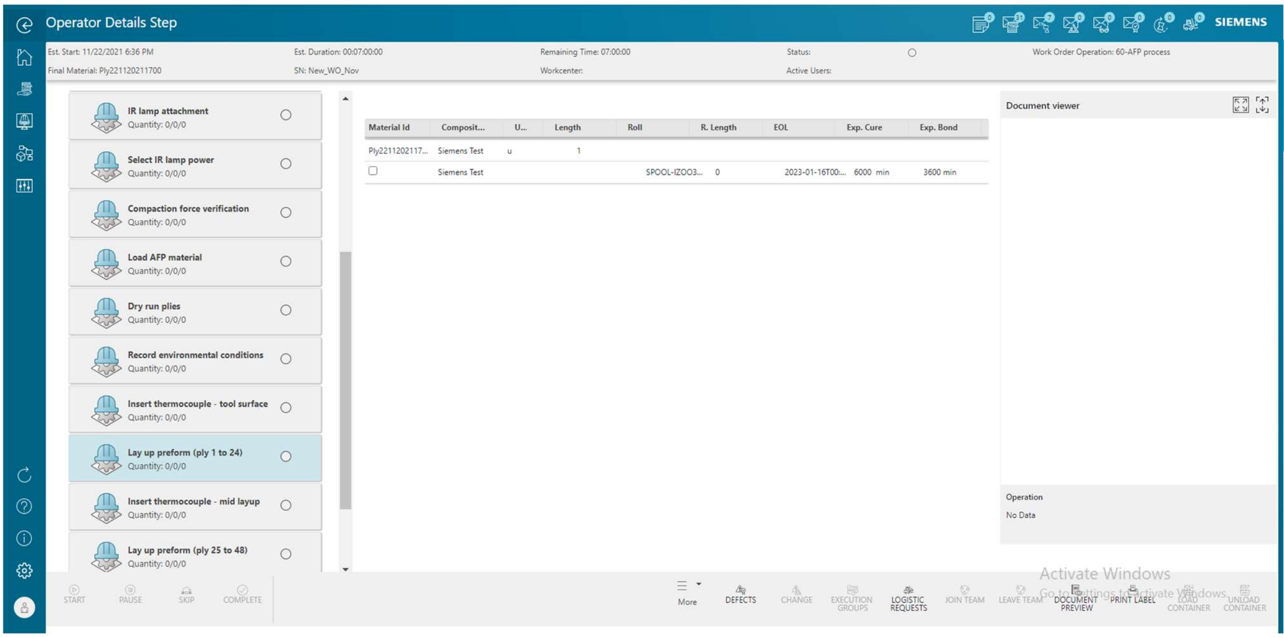


Figure 24 Material information retrieved in the Opcentre 'Operator landing'

Within this window, it is possible to update, in Plataine, the available material quantity that has been consumed during manufacturing (i.e. the remaining material stock) or request additional material spools if required. Thus, the data can be easily captured and updated as the operation is completed in Opcentre.

Once the work order steps and operations are signed off in Opcentre and the process is completed in APS, the material will be released back in the 'Material Smart Selection' environment. This window is a live catalogue of the available materials that can be used in any future work order.