DIGITAL ENGINEERING
TECHNOLOGY & INNOVATION

Delivering Right Every time Manufacturing, Self-Adaptive Manufacturing Processes

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Glossary

AI – Artificial Intelligence

ML – Machine Learning

SAMP – Self Adaptive Manufacturing Process

PFMEA – Process Failure Modes and Effects Analysis

MQTT – MQ Telemetry Transport

OTS – Off The Shelf

Executive Summary

Self-Adaptive Manufacturing Process (SAMP) is a specific realisation of a Digital Twin that aims to deliver “right every time” manufacturing. It is a concept that, when deployed effectively, can automatically control, in real-time, key manufacturing parameters to positively influence the outcome of manufacturing processes. This report lays out the concept of SAMP and how it has the potential to transform manufacturing, discussing the challenges of deploying SAMP that the Digital Engineering Technology & Innovation (DETI) programme has found and sets out a proposal for addressing.

DETI is a strategic programme of the West of England Combined Authority delivered by the National Composites Centre, in partnership with the Centre for Modelling & Simulation, Digital Catapult, the University of the West of England, the University of Bristol, and the University of Bath. Industry partners include Airbus, GKN Aerospace, Rolls-Royce, and CFMS, with in kind contributions from UWE, Digital Catapult and Siemens. DETI is funded by £5m from WECA, with co-investment from the High Value Manufacturing Catapult and industry.

Why?

Challenge

Manufacturing in the UK is seeing new and significant challenges, sustainability demands (captured by NetZero initiatives), recovering from the COVID-19 pandemic, BREXIT, energy prices and the continuing, rapidly evolving competitiveness from global markets.

Ultimately, these challenges are applying new levels of pressure on the UK engineering and manufacturing sector. This is realised through ever increasing demands in the following areas:

- Cost per product challenges to remain competitive
- Efficiency of production to meet sustainability demands:
  - Efficient energy use
  - Efficient use of raw materials (no or low waste)
  - Efficient use of workforce
- Demand for novel/higher-performing products to remain ahead of the competition

One of the ways to meet these demands is to develop higher-complexity manufacturing processes. With these types of processes becoming more prominent, ensuring manufacturing success is even more critical i.e. to avoid producing parts that require rework or scrapping (due to the inherent expense of the process and the part being created). This can be summarised as; **There is a need to produce more right every-time manufacturing, on more challenging processes.**

Self-Adaptive Manufacturing Processes (SAMP), a specific realisation of Digital Twin, are processes that have been enabled to overcome manufacturing variation and deliver right every-time products. This is particularly pertinent to sustainability demands where effort and energy cannot be spent on producing parts that require rework or scrapping. SAMP is delivered through the Digital Transformation of a given manufacturing process, this report discusses the particulars of SAMP.

Digitalisation and Digital Transformation

Before SAMP is discussed in detail, a brief introduction to Digitalisation and Digital Transformation terminology, opportunities and blockers.

Digital Transformation is the act of evolving a business's structure and processes to get the best of digitalisation.

Digitalisation leverages the ability of digital technologies to acquire data and assess it, thus helping to make better decisions and enabling new business models. For engineering and manufacturing, Digitalisation means acquiring data from across the product development lifecycle, design to manufacture and through service to end of life, in order to make better product-related decisions and improvements and unlock new business-related opportunities. Digitalisation is now a viable route for a wide range of business improvements.

Previously this wasn't the case due to the expense and difficulty of deploying digital technologies. The growth of readily available digital technologies and an increase in collective understanding, and associated skills, means that these technologies can now be leveraged to achieve transformational changes in businesses.

Why?

The value to be gained from Digitalisation in regard to engineering and manufacturing has multiple dimensions and potentially vast returns. However, Digitalisation is not without its difficulties. Whilst the opportunity for success has unbounded potential for engineering and manufacturing, this is dependent upon the correct Digitalisation being achieved. 2 key blockers to digitalisation are identified:

1) Failure to Launch – With so many potential digital technologies and the hype and speed by which these technologies are evolving, many companies simply get confused and tend to avoid launching digital transformations all together.

2) Failure to land – Companies may have implemented a digitalisation pilot or proof of concept, but the resulting Digital Transformation proves expensive and does not produce the expected return on investment, which ultimately lowers industrial confidence.

Digital Twins

When discussing Digitalisation in relation to manufacturing and engineering, Digital Twin is a theme that is frequently mentioned.

Digital Twin is a powerful concept that has been widely publicised and has been subject to broad interpretations, because SAMP is a specific type of Digital Twin it is worth providing clarity around the topic of Digital Twins.

There are many different definitions for Digital Twin, some of which are contradictory. The AMRC ([1]has completed significant work to alleviate this issue, clarifying the Digital Twin definition with: ***"A live digital coupling of the state of a physical asset or process to a virtual representation with a functional output"***. This is a very broad definition driven by the fact that the use cases of Digital Twin are so varied, with each use case having different objectives, or ways of achieving that objective.

With this in mind, the DETI promotes SAMP as the specific realisation of a Digital Twin with the explicit objective of delivering "right every time" manufacturing processes.

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[1] *AMRC, "Untangling the requirements of a Digital Twin," The University of Sheffield, Sheffield, 2020.*

What?

Self-Adaptive Manufacturing Processes

As already mentioned, Self-Adaptive Manufacturing Processes (SAMP) is a specific realisation of Digital Twin which can control and overcome manufacturing variation and deliver right every-time production.

To achieve this, a traditional manufacturing process and its associated systems are

1) Digitally modified to provide the ability to acquire quality controlling process data in real-time (the sensor array).

2) Process data is then used to assess whether the process is progressing/performing as it should be or not (the process model, deploying in most cases AI/ML techniques).

3) If this assessment raises a concern that the process isn't progressing/performing as it should then the manufacturing process, automatically and in near real time, is sent commands via the control system to change its behaviour to steer the process to a successful outcome.

Existing Manufacturing vs SAMP

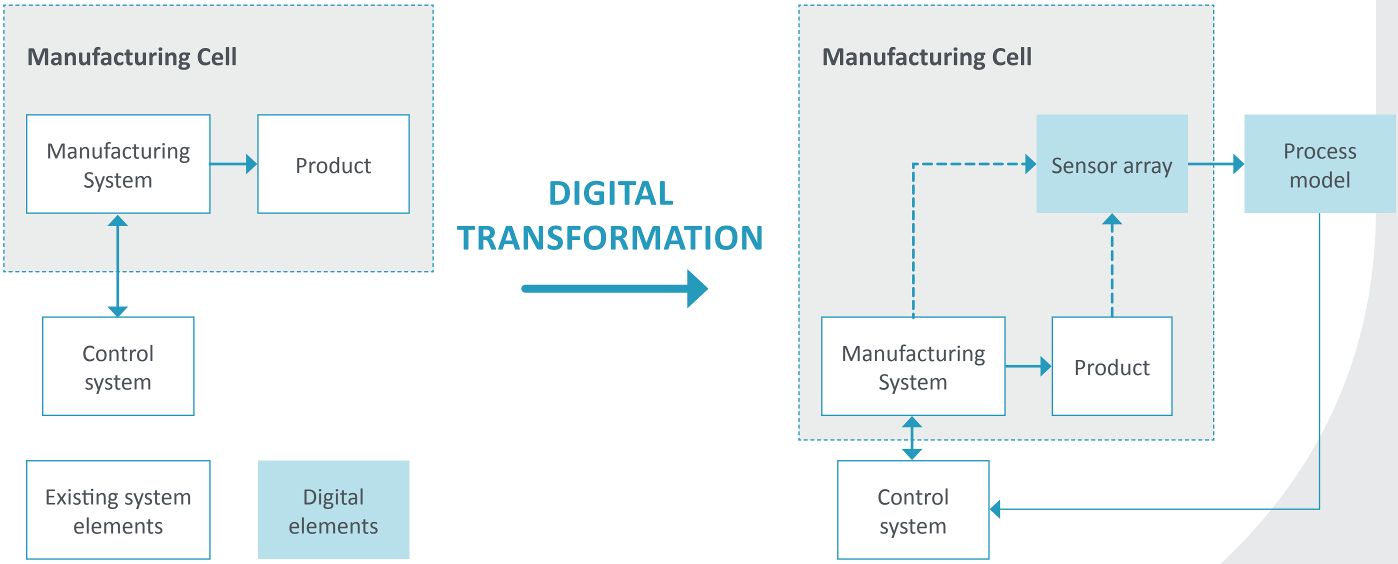


Figure 1 shows the system diagram for SAMP

Figure 1 is split into two parts where the LHS shows a simplified system diagram of a generic manufacturing cell, and the RHS shows the transformation of that cell to SAMP.

The generic manufacturing cell represents core elements of any manufacturing cell. For example:

- In the case of a fully manual operation, the human operator forms the control system, and the manufacturing system encapsulates any fixtures and tools they might use. The product is the item they are imparting work on.
- In an automated robotic system, the manufacturing system would consist of the robot and the associated tooling, the control system would be the cell controller, and the product would the object being worked on.

Figure 1 also shows the additional digital elements that are required to create a SAMP, these elements are:

- The sensor array
- The Process model
- An interface from the process model to the control system

Sensor Array

A sensor array is required to capture the influential process parameter data. It must be correctly specified to capture this data at the right fidelity and frequency as to completely characterise the process. Furthermore, careful consideration must be made to how the sensor array will integrate within the domain of the manufacturing system. This is an important element because without accurate data at the right frequency the process control cannot be achieved. Further to this, care must be taken not to over-engineer the sensor array and capture too much data. This can create confusion in the process model, resulting in incorrect control of the system.

To correctly specify a sensor array, expert process knowledge is required. DETI has refined Process Variable Mapping methods to enable engineers to capture this expert knowledge in an organised way so it can easily be applied to the function of specifying sensor arrays.

The type of sensor array used for a particular SAMP depends on the particulars of that manufacturing process. There is not a one-size-fits-all sensor array. However, DETI has gone some way to defining a common workflow that can be applied to any process to enable sensor array specification. This workflow covers the development of sensor arrays from requirements definition, through to integration with the manufacturing process.

Process Model

The process model has 2 key functions:

- **Ingesting** the process data generated by the sensor array and **evaluating** process performance.
- **Predicting** if the current process performance is likely to result in a successful outcome.

Similarly to the sensor array, the process model requires expert knowledge to develop it. Critically, what needs to be understood is what success looks like, and how different processing parameters influence success. This knowledge can be informed by expert operators, process engineers and simulation, but ultimately this needs to be "codified" into a digital model that can control the process successfully. The Process Variable Mapping workflow can be applied to capture the parameter influence over the process outcome.

The process model itself will vary in complexity dependent upon the application. A complex manufacturing process might benefit from using nonlinear or even AI/ML based models, whereas simpler processes will only require basic logical or numerical based models. In either case the model must be capable of being run at a speed where the frequency of model output is fast enough to react to the process.

What?

Interface

The interface element of the system is responsible for passing the control instructions back to the manufacturing cell control system.

It is possible that for a particular manufacturing process several different pieces of equipment might form the complete manufacturing system. In this instance, the control model will need to have an interface with the equipment it needs to provide instruction to.

It's worth noting at this point, that the manufacturing system must have adequate physical attributes to control the process to the model's demands. For example, if an injection moulding manufacturing process is having a SAMP deployed on it, then the process model might need to control the injection system and the tool heating. However, if the tool heater does not have adequate means to be controlled, then the SAMP deployment will not be successful. So, it is at the interface element where real hardware modification might have to be completed to enable SAMP.

SAMP VS Control Systems

The SAMP concept can be easily confused with Closed Loop Control systems, which have been in use in industry since the 1950's.

There are three key differences between closed loop control systems and SAMP:

- The first difference is the setpoint (the desired condition), closed loop control uses a user provided setpoint as the target for the control system, in SAMP the setpoint is dynamically changed based on the assessment of real-time manufacturing process performance data (provided by the sensor array) as assessed by the process model.
- The second difference is that the control systems are often developed to control a single element. In a SAMP all the process elements are controlled from a single model, thus making SAMP the overarching controller of a process.
- Thirdly, a closed loop control system sends control signals in relation to a system element. In SAMP, control commands are generated in relation to the entire manufacturing process performance, to control specific manufacturing variables.

To further demonstrate these differences please see figure 2:

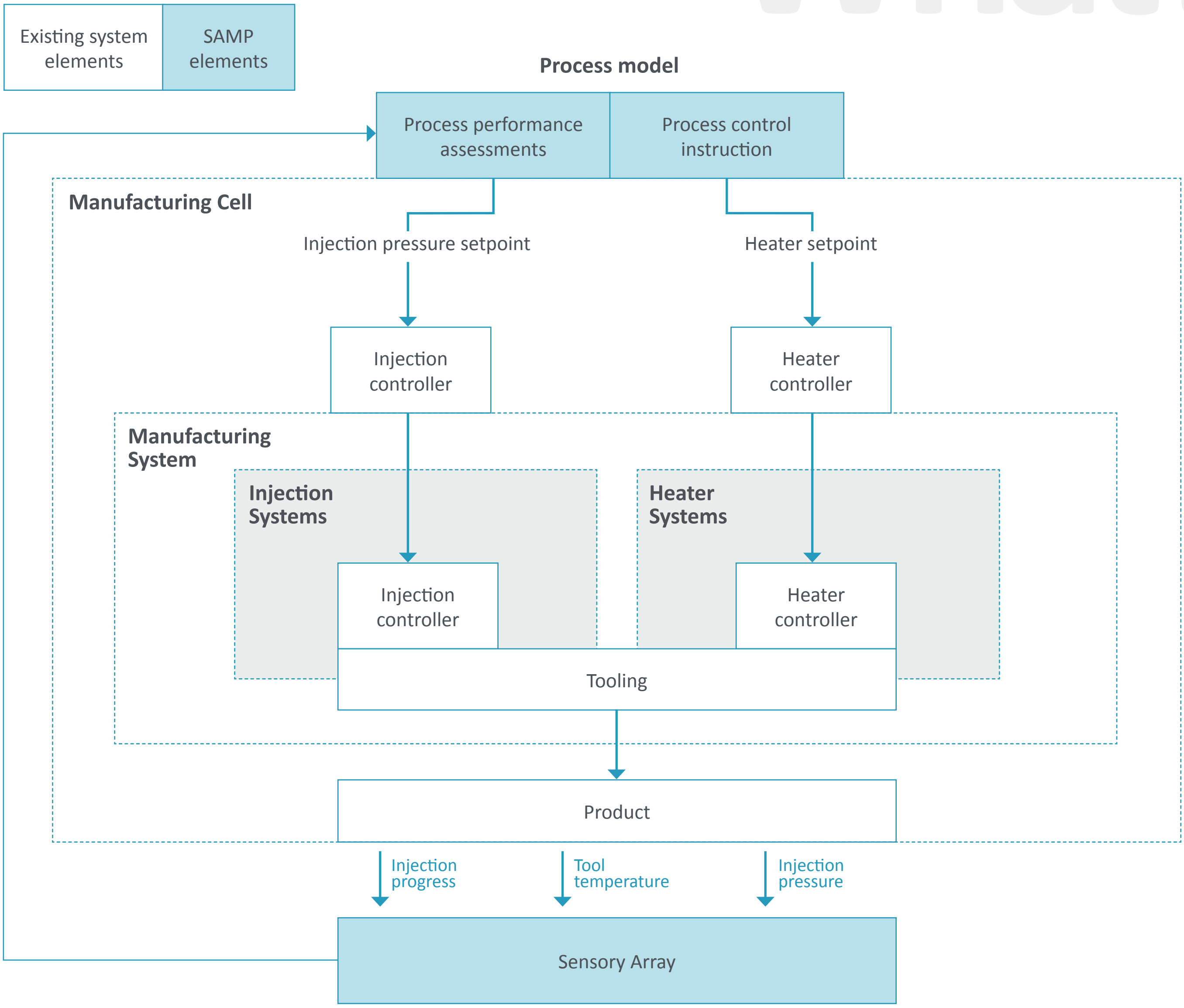


Figure 2 An example SAMP schematic for injection moulding

The Benefits of SAMP

The ultimate benefit of SAMP is to produce right first-time manufacturing.
This has the following associated gains:

- Lowers cost of production due to less scrap and rework
- Efficient production to meet sustainability demands:
  - All energy is directed towards making products of acceptable quality, every time, rather than on scrap parts that do not see service
  - All raw materials used are directed towards making products of acceptable quality, every time, rather than on scrap parts that do not see service
  - All workforce effort is directed towards making products of acceptable quality, every time, rather than on scrap parts that do not see service

How?

Delivering SAMP

The process of delivering SAMP requires a diverse and integrate team with the following skillsets and approach (role titles and specific scope of each role may vary in organisations, but the capabilities of the team and the activities they perform, will be relatively consistent):

PROJECT TEAM:

Project stakeholder/ primary customer:

- Manufacturing Engineer

Digital delivery team:

- Digital Systems Integrator
- Solutions Architect
- Data Scientist
- UX/visualisation Engineer

Traditional engineering team:

- Process Modelling Engineer

PROJECT DELIVERY STAGES:

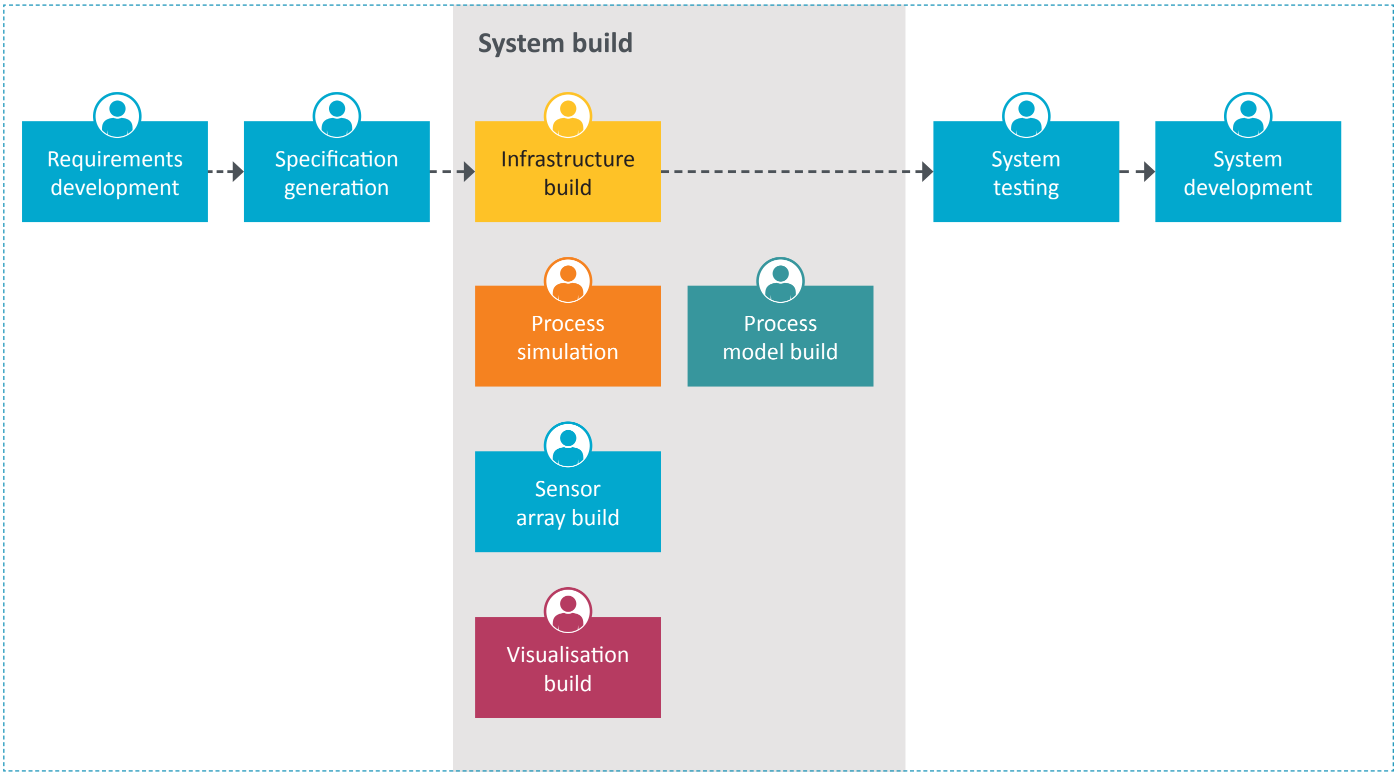


Figure 3 Systems engineer approach for SAMP

How?

Manufacturing engineer

The manufacturing engineer is the owner of the process that SAMP is being deployed upon. They act as the primary customer, and ultimate stakeholder, to validate the value of the solution and champion the change in the business.

They also act as the gateway for expert process knowledge. It is their responsibility to provide the digital delivery team (via the Digital Systems Integrator) with expert process knowledge either through chairing meetings with process experts or as the provider of process knowledge from PFMEA's/Value stream maps etc.

Digital Systems Integrator

The main project engineer that is responsible for delivering SAMP to the customer. Given this, a strong relationship between the Manufacturing Engineer (primary customer) and the Digital Systems Integrator is required. The Digital Systems Integrator is also the owner of the following activities:

- Requirement's elicitation, capture and development (including Process Variable Mapping)
- Specification generation and release
- The overall system build, liaising with the rest of the digital delivery team
- The testing activity
- The solution deployment

They are also responsible for developing the sensor array.

Solutions Architect

A Solutions Architect creates the overall technical vision for the IT system that will enable, support, and host the digital system. They design and build the IT infrastructure, liaising with the Digital Systems Integrator to understand the purpose of the whole digital system and the intent of the individual elements of the system. The Solution Architect will then select and implement (using inhouse IT resource or outsourced teams) the IT services that are required to achieve the behaviours of the intended system whilst meeting organisational IT requirements (such as security, licencing, software types, network protocols, etc).

Process Modelling Engineer

Responsible for building traditional manufacturing simulation models to predict the process performance. This simulation data is used as a starting position for training the process model and once real data is collected and the system performance has been evaluated, the manufacturing simulation model can be recalibrated to produce better results and perform what-if optimisation studies to inform improvements.

Data Scientist

Responsible for using the data generated from the simulation and raw sensor data to build a process model that can predict the process performance. Because this will be based upon sensor data from the sensor array, the Data Scientist must understand the link between the expected sensor data and that of the process performance. This model must also be able to generate the intervention instructions to steer the process, so an awareness of the intervention mechanisms is also required.

Visualisation/UX engineer

The engineer who develops the human interface and visualisation elements of the SAMP system. This is critical, as a thorough and intuitive interface is required for successful adoption of technology. It must be able to present relevant data in a simplistic fashion where a range of users can access the information they need quickly. But it must also provide a level of depth that allows users to delve into the working of the system so that they can build confidence that the system is behaving as expected.

If users are confident that the system is working, and they find the presented information to be useful and relevant, the technology adoption has a higher likelihood of being successful.

The Digital Transformation Journey to SAMP

Completing a Digital Transformation can be a daunting task, especially for organisations that are looking at Digital Transformations for the first time.

The Digital Transformation journey is shown below:

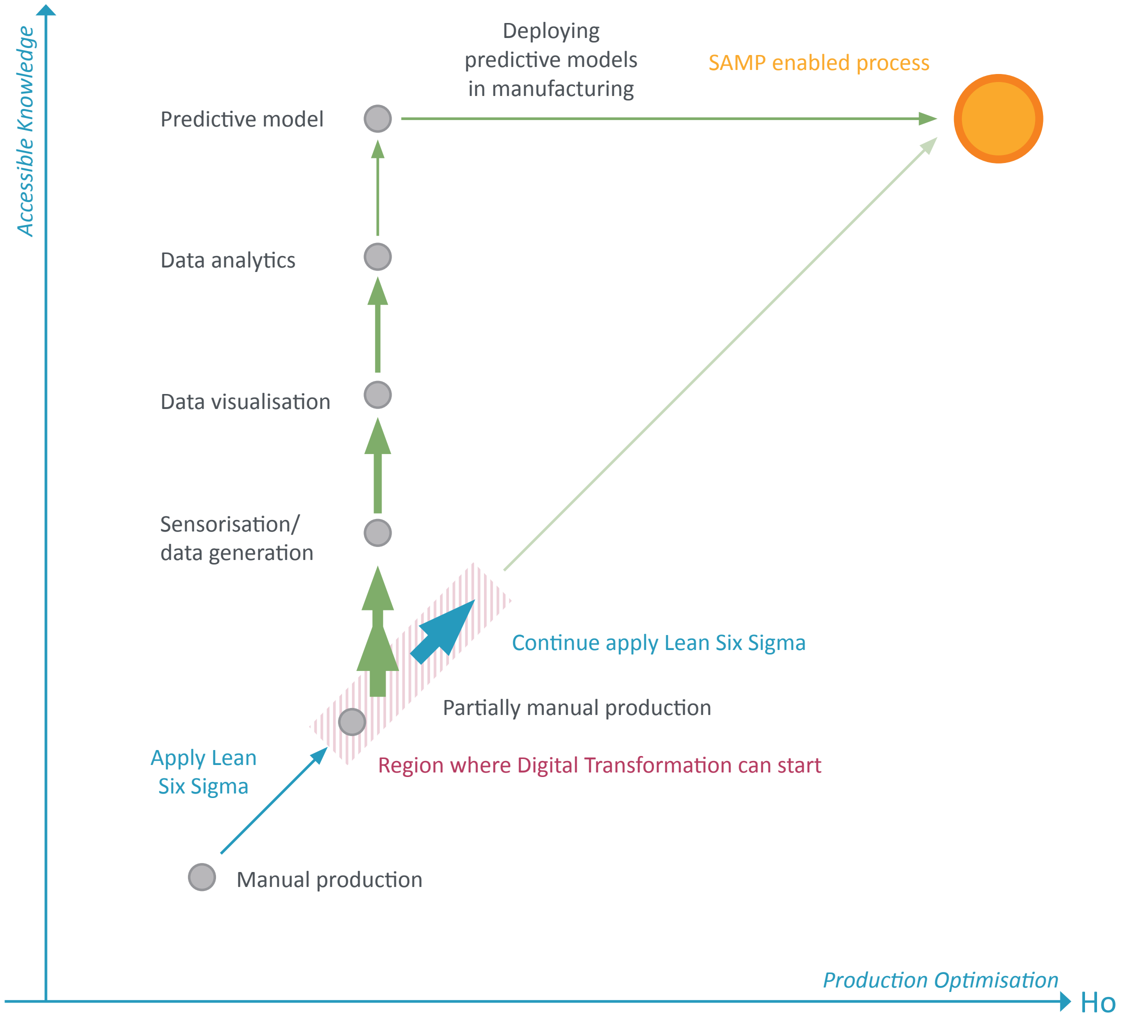


Figure 4 Digital Transformation Journey

The vertical axis represents the process knowledge that is grown, and made accessible, through the Digital Transformation journey. The horizontal axis represents the optimisation of a process. The thickness of the arrow indicates the effort required to move between the journey waypoints.

At the bottom left of this diagram a trajectory is shown that relates to the journey that an organisation would experience if they were to implement aspects of Lean Six Sigma. The tools and processes relating to Lean Six Sigma collate and present manufacturing knowledge, tools like PFMEA are a good example of this. The implementation of the output from these tools yields production optimisation gains. Using PFMEA as the example again, the implementation of the risk mitigations should result in fewer defects being created for a given process, thus improving the optimisation of that process. Therefore, the Lean Six Sigma trajectory plotted on this diagram is a diagonal line.

Overlayed onto this trajectory is the "region where Digital Transformation can start". This is a theoretical region that indicates that in order to complete Digital Transformation on a particular process it is best that some process optimisation is already completed. This is mainly because the information that is collated from these activities is very relevant to the digital delivery team and is the type of information required to design an effective digital solution.

This isn't to say that you can't start a Digital Transformation without this knowledge, however without this the effort to start digitalisation is even greater as process knowledge has to be elicited and developed from scratch.

From the "region where Digital Transformation can start" the Digital Transformation journey is shown by the green arrows.

The first thing to note is the difference between the traditional optimisation trajectory, given by Lean Six Sigma, and that of the Digital Transformation Journey.

Regarding the effort profile (indicated by the boldness of the arrow for each step), for Lean Six Sigma the start of the optimisation is relatively low effort with relative high yield. However, with further optimisation the gains are harder to achieve. This means that the Lean Six Sigma trajectory is one of diminishing return. With Digital Transformation, the effort is front loaded, meaning that with each waypoint achieved on the Digital Transformation Journey the gains potentially become exponential relative to effort, but to start with the gains are slow. Some of the reasons for this front-loaded effort profile are related to upskilling, but generally requirements elicitation exposes many interrelated questions that need to be answered for the specification generation to commence.

The Digital Transformation journey is also one where process knowledge must be made accessible before the optimisation gains from the implementation can be realised. This has the effect of making Digital Transformation projects quite high risk, which is why solution and project scoping is critical to establishing a successful project.

These two factors combined, mean that Digital Transformation is slow gain and high risk at the beginning, but has the potential to produce high impact gains for low effort further down the road.

The waypoints on the Digital Transformation journey are:

1st step Move from a partially optimised process to a sensorised process. This includes working out which variables need sensorising, specifying the sensors, building a sensor array and connecting this to a platform where this sensor data can be made available, such as an IoT platform

2nd step Move from a sensorised process to a process with data metrics visualised: The process data from the sensors can now be seen in a format which is useful for the particular process. It might be that this is a simple dashboard with charts, or a more complex 3D visualisation where data is overlayed onto CAD models.

3rd step Move from visualisation to analytics: the process data can be analysed to discover a deeper understanding of the process performance. Doing this after visualisation is advantageous because the visualisation might have brought certain trends or parameters to the attention of the process owners that were previously ignored or assumed to be less influential than in reality.

4th step Move from analytics to predictive: once a deep and thorough understanding of process performance has been established, then predictive tools can be used to predict what might occur in a process before it has happened. This is the level of understanding that is required to deliver SAMP systems

5th step Once predictive tools are established then the process of implementing intervention strategies can be completed, thus enabling a SAMP system.

A staged approach to progressing Digital Transformation to SAMP is recommended:

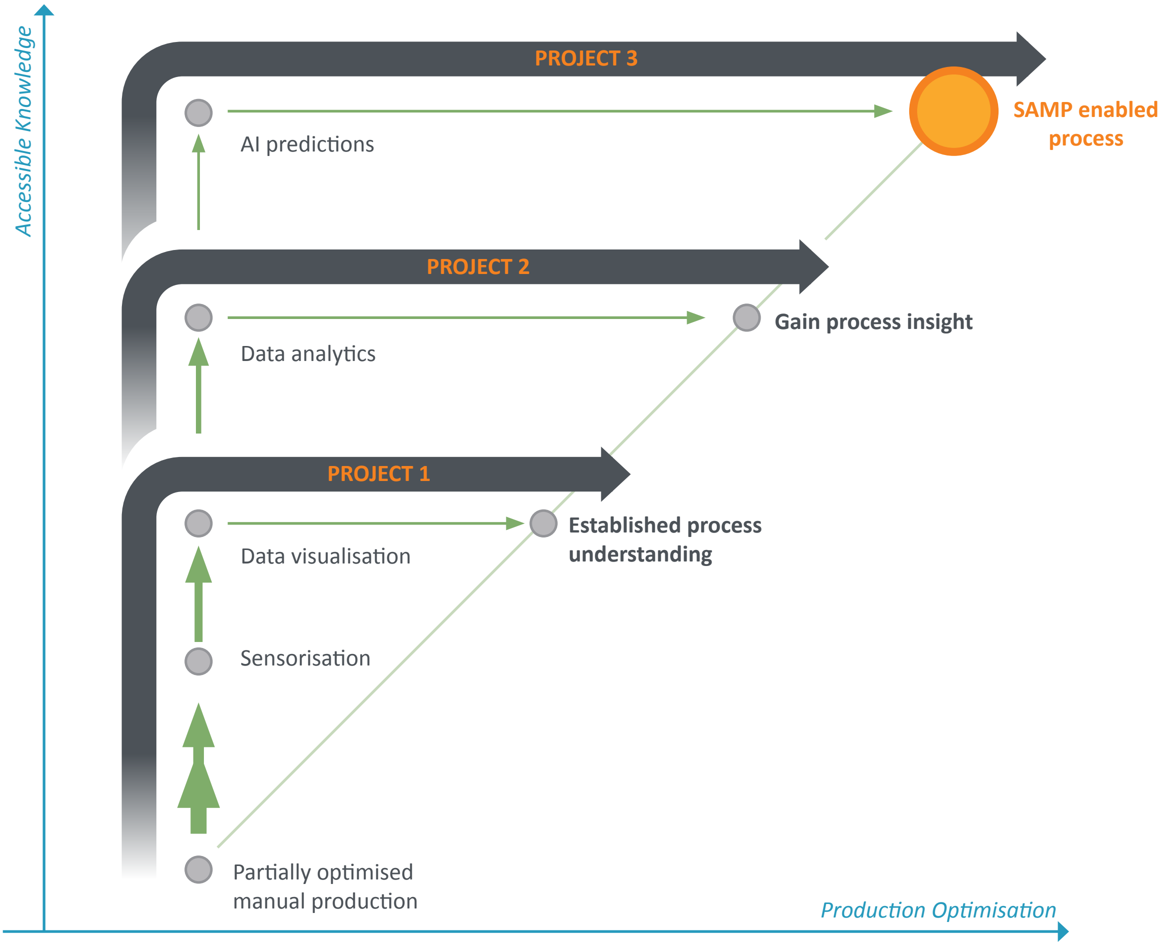


Figure 5 Stage approach to Digital Transformation

The staged approach splits the Digital Transformation Journey to SAMP into 3 distinct projects, where the first project is the highest risk (fail fast) but also the lowest gain. The second project builds on the sensorisation and visualisation elements developed in the first project, by applying analytics to the data gathered. The final project develops the predicitve element and the adaptive controls required for SAMP.

This approach both derisks the journey from a cost and time to ROI perspective, but also builds confidence in the digital solutions as they gradually mature to be self adaptive i.e. ensuring SAMP adoption becomes more sticky...

Barriers and the route to achieving widespread SAMP

Whilst direction through the Digital Transformation journey is useful, there are still many barriers that need to be overcome for SAMP to be an achievable widespread solution for a wide range of industries.

Business Barriers

- ROI
  - There is no justified ROI evidence base to build a business case for SAMP across multiple different use cases
  - There is unknown investment risk due to lack of upfront understanding on adoption of SAMP costs
  - There's a high investment risk due to unquantified value from successful adoption of SAMP
- Skills/knowledge related to adopting SAMP
  - There is a lack of readily available skills to manage the adoption of SAMP
  - There is a lack of informative best practice documentation to guide people through successful adoption of SAMP
- Skills/knowledge related to digitalisation
  - Lack of skills/knowledge on how to identify and prioritise opportunities to digitalise

Technical Barriers

- Sensorisation
  - The skills and tools required to develop a well specified sensor array, critical to the success of SAMP, are not well established
- Modelling development
  - Best practice for developing advanced predictive process models is not defined
  - The models also depend on the availability of simulation models for a particular process
  - These models need to be detailed enough to control complex processes but able to run on industrial controllers in real time at a rate faster than the rate of process deviation
- Legacy equipment
  - For SAMP to be widely adopted it needs to be capable of being deployed on legacy manufacturing equipment that is already in production use.
  - This means that the integration of SAMP must be as seamless as possible to create minimum disruption in live production environments
  - Manufacturers do not have access to best practice on modifying equipment to deploy SAMP
  - For some legacy equipment, that is under service contract or supplier signed performance clauses, deployment of SAMP risks voiding these contracts and therefore shifting liability onto manufacturers rather than equipment suppliers. Common agreements on SAMP between manufacturers and equipment suppliers need to be developed

Software

- OTS
  - OTS opensource (or multi-vendor) software needs to be bolted together with homemade scripts to achieve SAMP

IT

- Digital Infrastructure
  - There is some best practice on deploying digital infrastructures in real world industrial environments (factory+) but, it does not have feature specific best practice around SAMP

To overcome these barriers the following roadmap has been suggested:

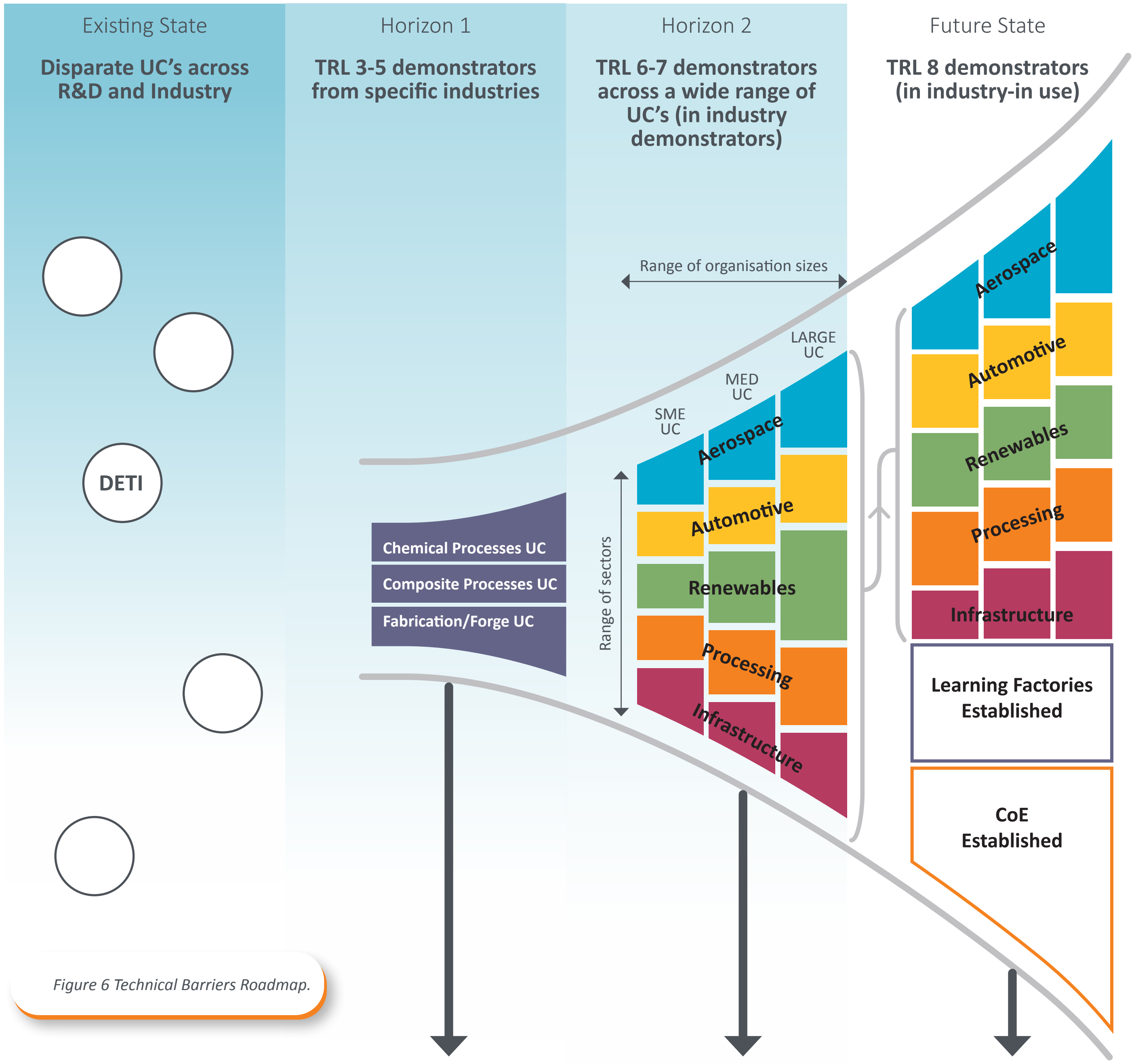


Figure 6 Technical Barriers Roadmap.

Awareness	• Wide range of digital jargon	• UC's under 1 banner • Website launched • Event tour	• Factory tour roadshow	
Business Cases	• No firm value propositions	• ROI templates • Justified costing estimates • Justified value propositions	• ROI template refined • Costing validated • Value propositions validated	• Business case process documented
Best Practice: • Legacy eqpt. • Sensorisation • Model dev	• No method for dealing with legacy eqpt • Sensorisation workflow developed • No model dev workflow	• Develop methods of dealing with legacy eqpt • Establish sensorisation workflow and tools • Develop model dev workflow	• Test BP's	• Refine BP's
Training + Skills development	• Training across digital is disparate and not solution focused	• Training themes and course types defined • Training partners identified	• Training course developed • Learning factories defined	• Training courses released • Learning factories launched
Digital Infrastructure	• Initial best practice captured in Factory + (AMRC) • High level best practice not established	• Best Practice refined	• Mix of OTS and bespoke BETA solutions • BETA route to release defined	• Best practice documented • Platforms released
Software solutions	• Mix of OTS and user developed scripts	• OTS software only used • Development gaps identified • Development partners identified	• Mix of OTS and bespoke BETA solutions • BETA route to release defined	• Best practice documented • Platforms released
Support and Consultancy	• No clear sign posting • No consolidated offerings	• R&D support defined • Consulting partners identified	• R&D offering agreed • Consulting partner offerings developed	• Offerings and service and signposting documented

SAMP Case Study - Liquid Resin Infusion

Industrial Challenge

Liquid resin infusion (LRI) is a process used by the aerospace, automotive, marine and many other industries to create composite components. These can range from boat hulls to full aircraft wings, such as on the Airbus A220. It offers higher rate and lower cost production compared to some other methods used to make composites (such as prepreg moulding, which has higher material costs, and longer processing times) whilst still delivering high performance structures. The technique however is highly dependent on the skill of the operator, is very manual, and often produces many scrap components when developing new parts. It is also a very energy intensive process, so failures not only involve material, time, and financial resources, they are also costly in CO2 emissions.

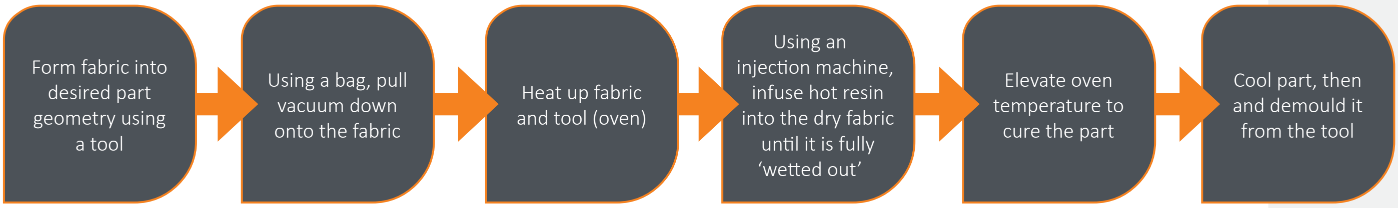


Figure 7: Stages of the LRI composite manufacturing process.

As industry grows its use of LRI, there is a need to improve the process to enable parts to be made 'right first time' and 'right every time'. In turn, this lowers the cost and time of developing new components and reduces the environmental impact of composite production by generating less scrap. These improvements to LRI composite manufacturing can be achieved through data analysis and automation of the LRI process by the application of digital and 5G technologies.

Digitalisation Process

Within this use case, the LRI process was developed by adding 3 key elements as part of the composite manufacturing technique, as described in Figure 1:

- These included a sensor array, to capture data during the manufacturing process
- A process model featuring a control model which ingested the data to make decisions to control the process
- A feedback system which implemented these decisions in the real world.

Additionally, a data visualisation system which displayed all process data to operators in real-time was developed to provide process insight alongside the SAMP solution. The digital technologies employed, as well as the utilisation of 5G, resulted in a self-adaptive LRI manufacturing process.

System Components

The use case was composed of two systems running in parallel, each based on a combination of at least one of the following 4 key components:

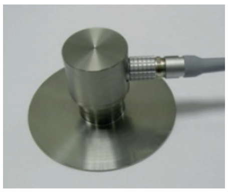
1. **Sensor Array**
2. **Process model**
3. **Feedback System**
4. **Visualisation System**

The SAMP system included collecting captured data from the **sensor array**, which monitored critical LRI process variables. From these monitored process variables, resin arrival status in particular was utilised by the **process model** to generate resin outlet line commands. These commands were then implemented by the **feedback system**, opening or closing the valves to control resin flow. The *SAMP System* therefore enabled automatic control of the LRI process elements.

The data captured from the **sensor array** also fed into the *Data Visualisation System*, alongside the **feedback system** and injection machine data. A combination of the data captured by the sensor array, feedback system and injection machine were displayed on cloud-based, real-time dashboards and fed into a part report once the manufacturing cycle was complete. The *Data Visualisation System* visualised key process data for the use of engineers, aiding process understanding.

Sensor Array Development

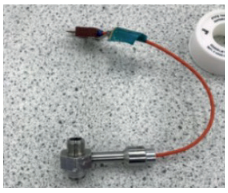
The sensors were 'activated' when in contact with the resin. The sensors themselves monitored only resistance and temperature directly. However, the Synthesites Sensor Control software converted these measurements into resin arrival status, Degree of Cure, Tg(Glass Transition Temperature), and resin viscosity in real-time. The sensors were integrated into the silicone bag to enable them to be in direct contact with the part during manufacture. The sensors and bag integration are shown in Figure 8 below.



In-Bag Sensors

Capable of monitoring:

- Resin arrival status
- Degree of cure
- Temperature
- Tg
- Viscosity



In line sensors

Capable of monitoring:

- Resin arrival status

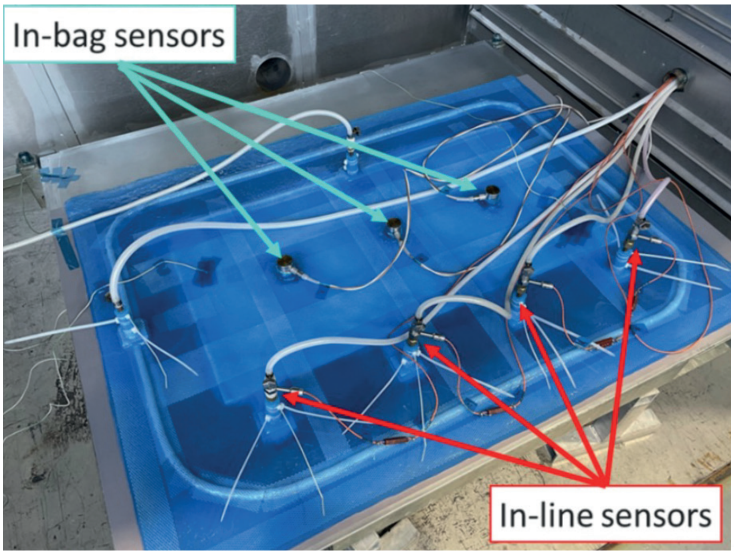


Figure 8: Depiction of the sensor array utilised during the case study.

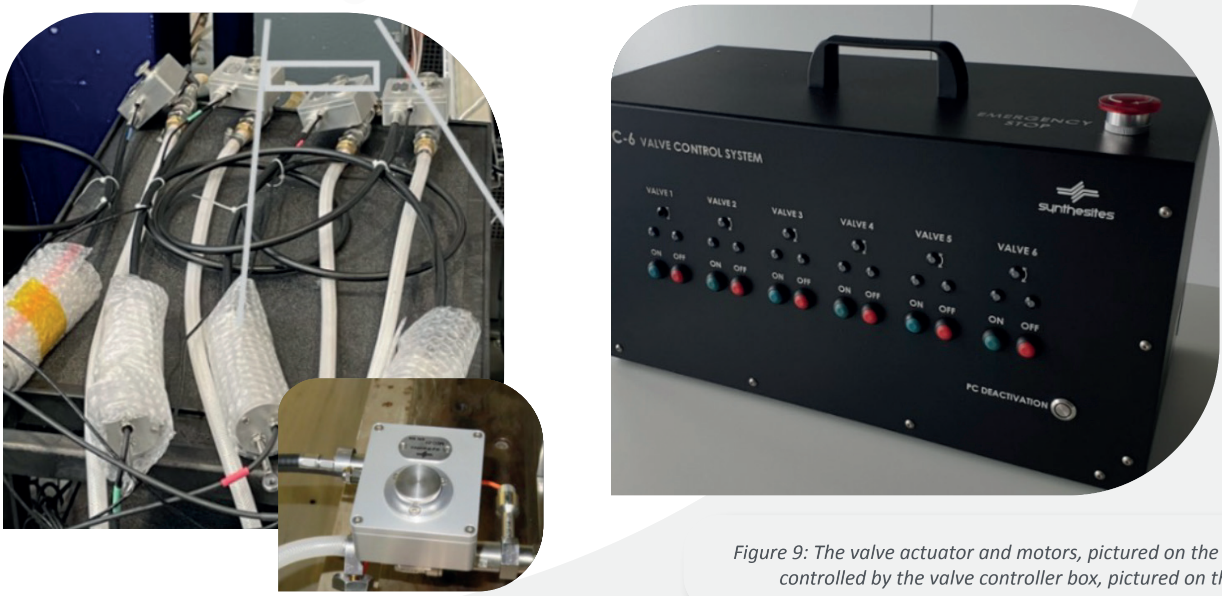
Control Model

A **control model**, hosted on a Windows 10 virtual machine, was composed of a custom developed Python script which packaged commands as MQTT messages. This MQTT message format could be read by the **feedback system**. In order to send and receive messages from both the **sensor array** and **feedback system**, the open source Mosquitto MQTT Broker was utilised, via which all sensor data and control commands were sent between the **sensor array**, **feedback system** and **control model**.

Due to the lack of geometric complexity of the part generated within this case study, the control model was relatively simple. However, the architecture of the SAMP system was designed to allow a future control model to replace the pre-existing model, with relative ease.

Feedback System

Four resin outlets were automatically controlled by the **feedback system**, which implemented **control model** commands to open or close the valves. The **feedback system** was composed of a number of components, including hardware and software. Hardware components consisted of a controller box and valve actuators, examples of which are shown in Figure 9.



Valve Actuators
Opens and closes resin valves

Valve Controller Box
Controls the valve actuators

Figure 9: The valve actuator and motors, pictured on the left, are controlled by the valve controller box, pictured on the right.

The valve controller box provided the power to engage the valve actuators, where the valve actuators, when paired with valve motors, physically opened and closed the resin outlets. When a valve was successfully opened or closed, a valve status message was relayed from the valve actuator to the controller box.

Visualisation

The Data Visualisation System generated comprehensive datasets on each part manufactured, from which engineers could make informed, data-driven decisions. This visualisation system was composed of three key elements, including Azure IoT Hub, a data warehouse and Power BI Dashboards.

Data collected via cable from the sensors was sent to the Azure IoT Edge, which served as an on-premises gateway or collector agent. From the Azure IoT Edge, all data collected during the manufacturing cycle was forwarded to the Azure IoT Hub via the 5G network. This data was then sent to the cloud-based Azure Datawarehouse via the internet, where all manufacturing data was stored.

Power BI Dashboards, hosted in the Azure cloud, were utilised to interface with and extract data from the data warehouse. This data was then displayed in real-time on live dashboards, as well as in a post-manufacture report dashboard as an easily digestible summary, as seen in Figure 10.

LRI
Job History

Select Job Name
5G LRI Part 2 (RTM6-4G)

Metadata
5G Encode [redacted]
Project Name Project ID
[redacted]
WO No. PM
[redacted]
Activity No. DIS Originator
NCC 22.00
Customer Ambient Temp
1,050.00 NCC
Ambient Pressu... Manufacture Loca...
[redacted]
TA Technicians
(Blank)
Notes

Status Changes

Status	Timestamp
Complete	8/26/2021 8:00:00 PM
In Progress	8/26/2021 2:53:23 PM
New	8/26/2021 9:25:34 AM

Events

Event	Data	Timestamp
in_bag_sensor2/resin_arrival_status	1	8/26/2021 3:01:45 PM
in_bag_sensor1/resin_arrival_status	1	8/26/2021 3:01:55 PM
in_bag_sensor3/resin_arrival_status	1	8/26/2021 3:01:59 PM
in_bag_sensor2/resin_arrival_status	1	8/26/2021 3:03:20 PM
in_bag_sensor1/resin_arrival_status	1	8/26/2021 3:03:29 PM

Figure 10: Visualisation of the LRI part report dashboard

Benefits

This use case aimed to reduce the risk and dependency on operator skill of the high value LRI manufacturing process by developing a system that could automate elements of the LRI process, utilising SAMP. In turn, process time and cost associated with developing new components, as well as their environmental impact, would be minimised.

A variety of benefits were realised from the digitalisation and automation of the LRI composite manufacturing process. The automation element of this use case yielded benefits such as labour cost saving and reduced process risk, each moving the LRI process in the direction of 'right first time' manufacturing.

Insight into the LRI process was achieved, resulting from the data collected and visualised. The enhanced data capture was leveraged for data driven decision making, which led to shortened cure cycles and an associated reduction in energy usage. In turn, this could lead to cost saving and improved environmental impact of the LRI composite manufacturing process.

Digital Engineering Technology & Innovation (DETI) is a research, innovation and skills initiative that brings together leading companies, technology disruptors and universities to push the boundaries of the digitally enabled engineering of the future, to help UK businesses maintain engineering leadership. DETI is a strategic programme of the West of England Combined Authority (WECA), delivered by the National Composites Centre (NCC) in partnership with the Centre for Modelling & Simulation (CFMS), Digital Catapult, the University of the West of England (UWE), the University of Bristol, and the University of Bath. DETI is funded by £5m from WECA, with co-investment from the High Value Manufacturing Catapult.

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