CLAMPS
Machine Learning in Automated Composite Manufacturing

NCC and CFMS Collaborative Project

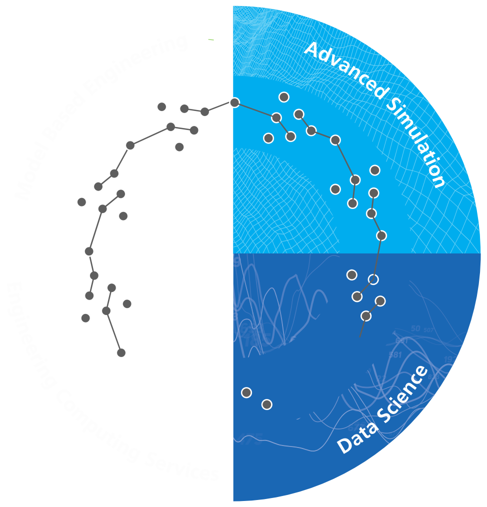
CFMS Business Lines

Model Based Engineering – constructing efficient computational architectures for system design that provide the foundation to establish an integrated product digital twin

Advanced Simulation – performing mathematical modelling of the physical world to derive an improved understanding of the performance of industrial products

Data Science – deriving the maximum value from digital simulation, physical test or process operations by applying artificial intelligence methods to reduce cost and enhance performance

Engineering Computing Services – the heart of CFMS capability, an HPC resource & IT Laboratory providing a secure, agile experimental platform to test industrial M&S solutions



CFMS Vision : to be the recognised, independent and trusted digital test bed for the design of high value engineering products and processes

Business Case

Why

Back in the 80's when A320 was first designed, nobody had expected that the Aircraft would be such a big success in the future.
Hence its design was mainly driven by **Performance** criteria (e.g. payload, fuel burn and range) rather than **High Volume Production** criteria.
But given the **HUGE** success of single aisle aircrafts, the next generation of single aisle aircrafts need to meet both Performance and industrial requirements.

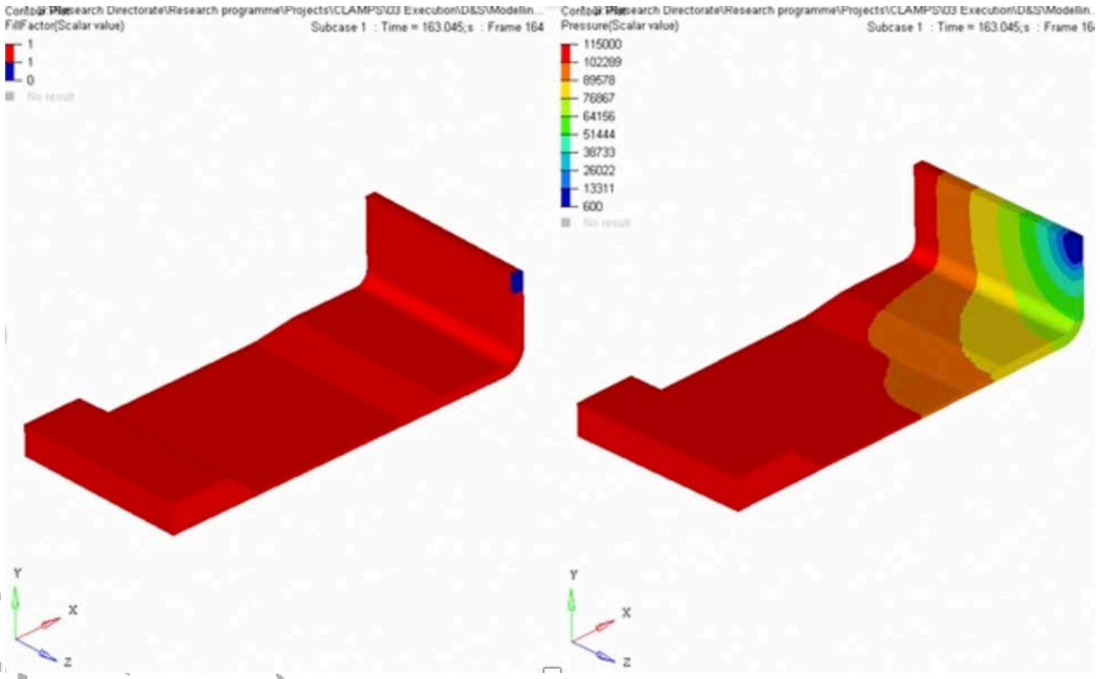
What

Dry fiber composite manufacturing with resin infusion technology **promises to have the potential** to meet the industrial requirements of next generation single aisle aircrafts. **BUT** given that it's a relatively novel manufacturing process a quicker route to **validate** the potential and **mature** the process is required.

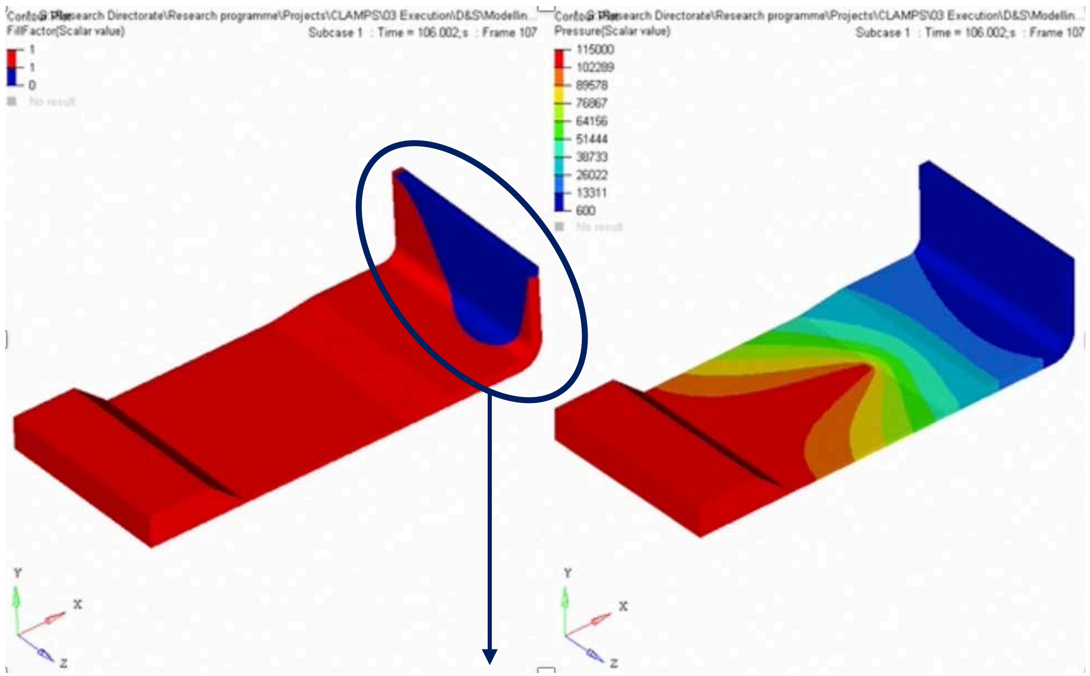
How

Combining **Machine Learning** with **Manufacturing Simulation** (as shown in subsequent slides) will lead to accelerated novel manufacturing process **learning curve** for shorter '**time to market**' lead times and also provide insights into improving process and product quality.

Resin Flow Simulation in Composite Part



Good Resin Coverage

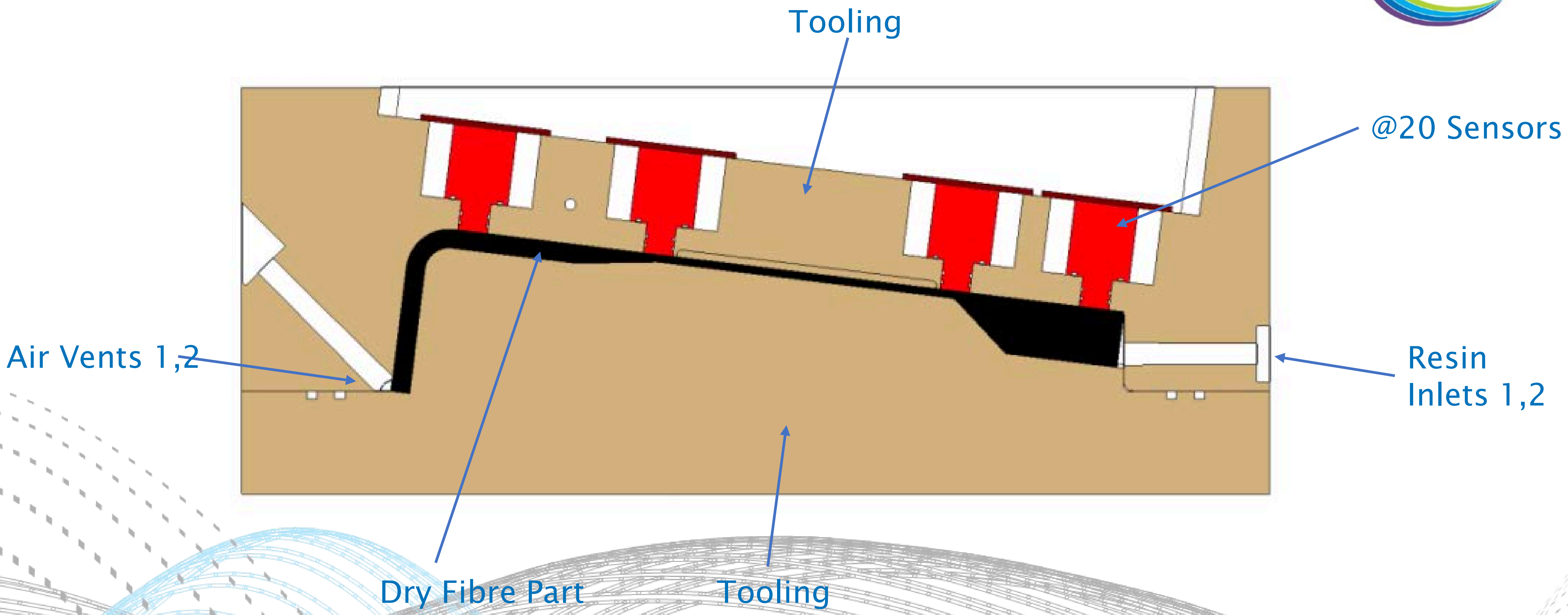


Poor Resin Coverage

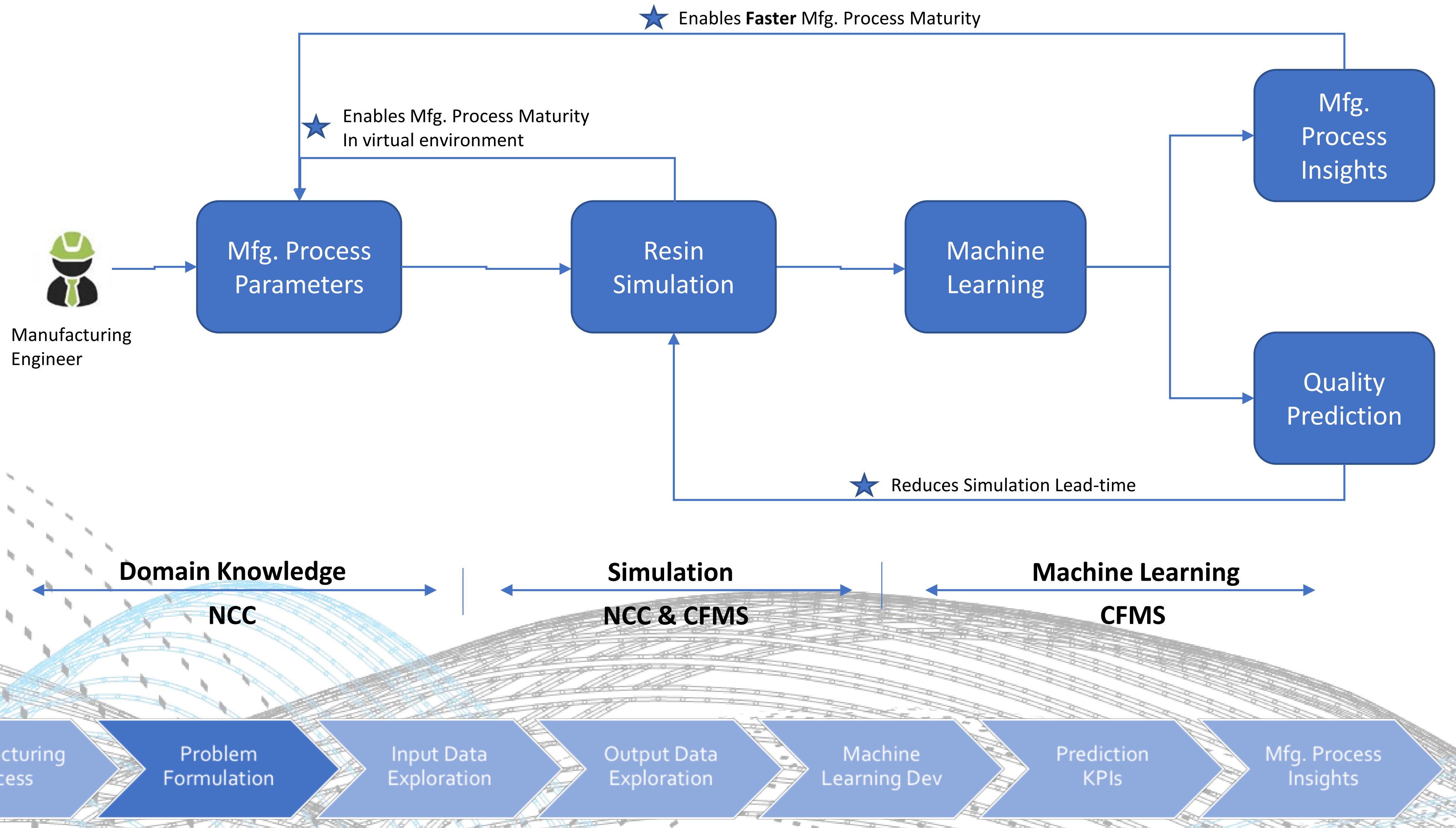
Video Source : NCC

Manufacturing Process → Problem Formulation → Input Data Exploration → Output Data Exploration → Machine Learning Dev → Prediction KPIs → Mfg. Process Insights

Mould Schematic

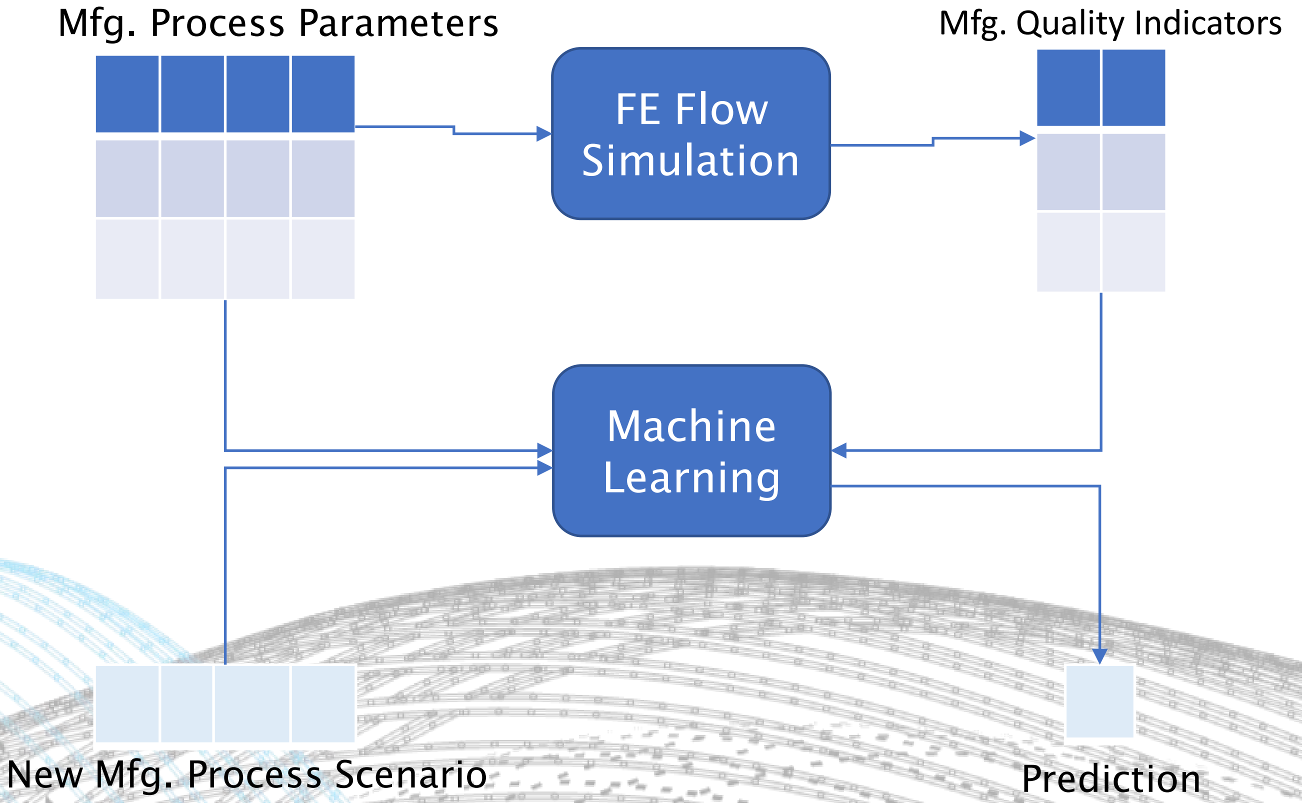


CLAMPS Overview



CLAMPS Objective

- Using resin flow simulation data , develop a machine learning model that predicts the quality of the composite part using manufacturing process parameters as a leading indicator



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Input Data For Machine Learning

16 Manufacturing Process Parameters

Mfg. Process KPIs

15000

TCI1	TOI2	TCI2	TOV1	TCV1	TOV2	TCV2	RT1T	RT2T	VFZ1	VFZ2	VFZ3	PI1	PI2	PV

Simulation Inputs

Unfilled Nodes	Fill Time

Simulation Outputs

Manufacturing Process → Problem Formulation → **Input Data Exploration** → Output Data Exploration → Machine Learning Dev → Prediction KPIs → Mfg. Process Insights

Simulation

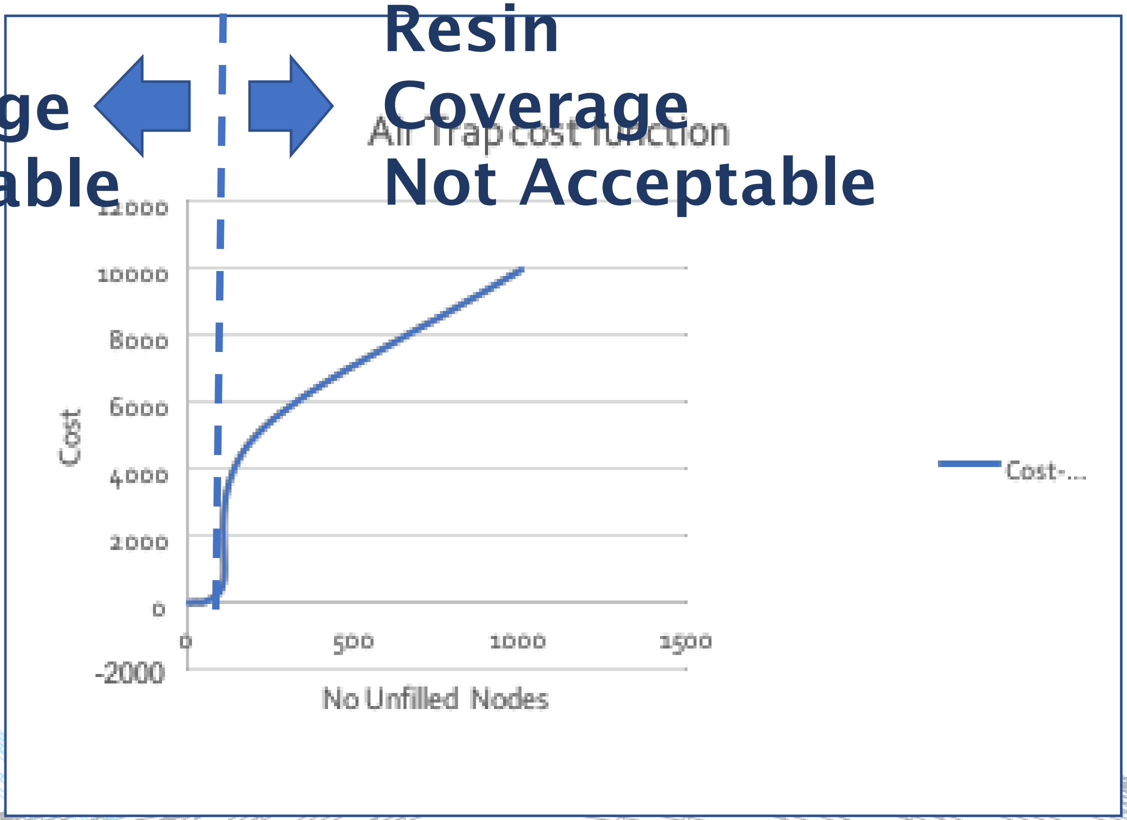
- Embarrassingly parallel RTM simulation application (single threaded).
- Complete DoE sweep – no ’nudges’
- Run on CFMS in-house HPC cluster - ~100k core-hours

Manufacturing Quality Criteria

200 unfilled nodes

Resin Coverage Acceptable

Resin Coverage Not Acceptable



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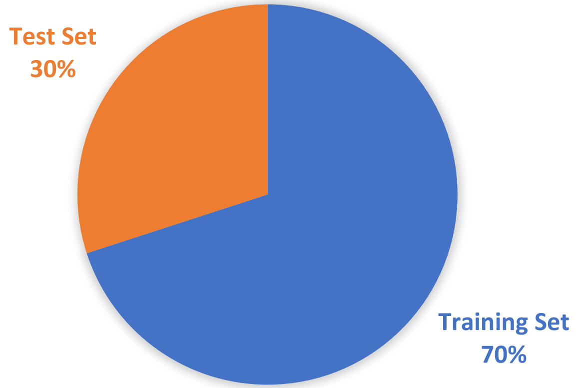
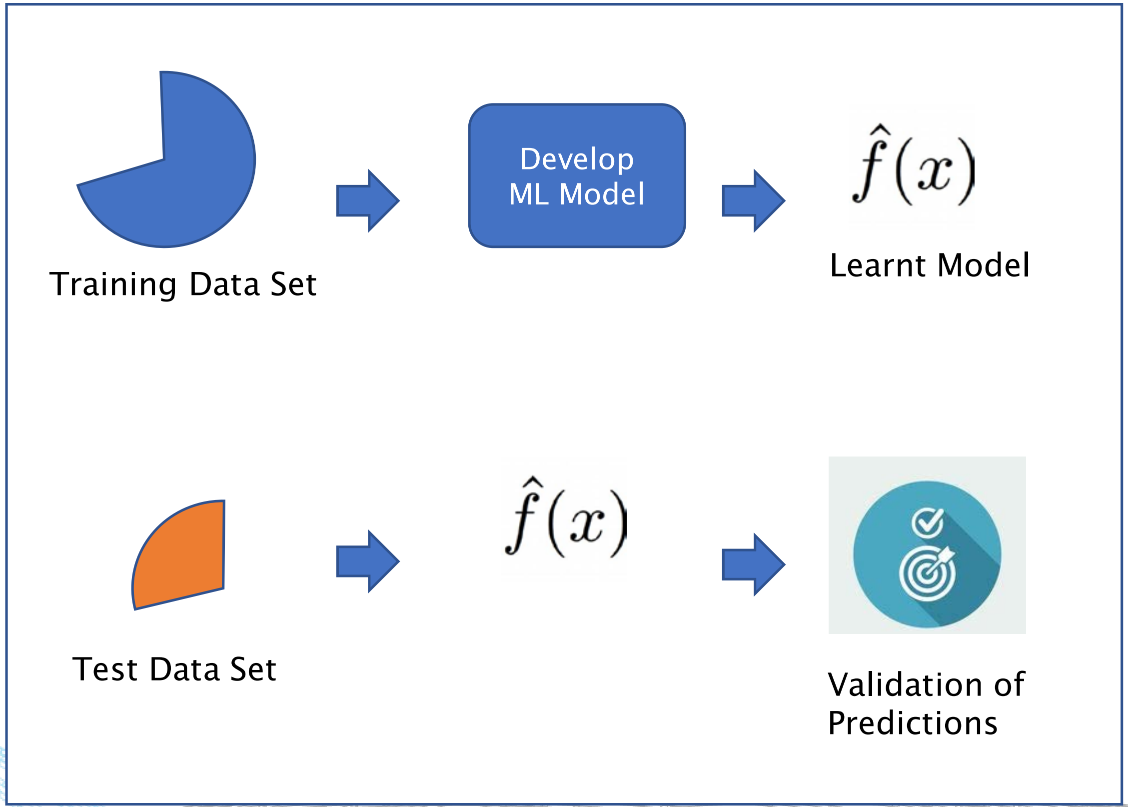
Machine Learning Data Split

MACHINE LEARNING DATA SPLIT



15,000 simulation data set is split into training set and test for machine learning model development and testing

ML Development Process



Machine Learning Model Prediction KPIs

Exam Question :

Given a set of manufacturing process parameters, Can we predict if the RTM process can achieve satisfactory resin coverage

Machine Learning Prediction \ (Simulation) Ground Truth	Good resin Coverage	Poor resin Coverage
Good resin Coverage	**True Positive** = 90.1 %	False Positive = 2.4 %
Poor resin Coverage	False Negative = 9.9 %	**True Negative** = 97.6 %

* Using basic Machine Learning model tuning

Execution Times Comparison

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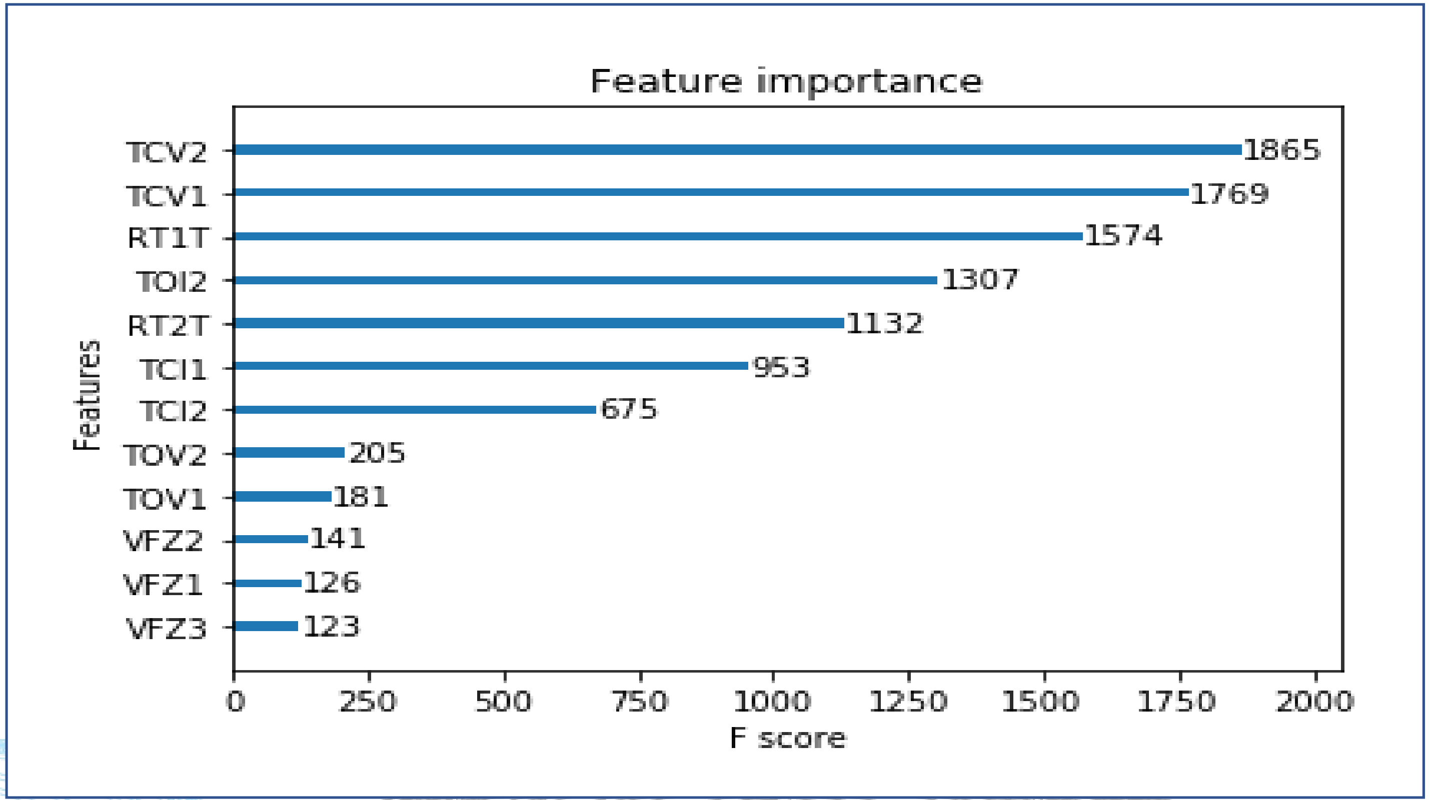
	FE Flow Simulation	Machine Learning Prediction
Iterations	5000	5000
Hardware	HPC Cluster (~10 nodes)	Standard CAD Laptop
RAM	128 GB	16 GB
CPU	Intel Xeon E5-2650v4	Intel Core i7
Lead Time	**100 hours**	**3 minutes** (plus one off training lead time of 15 minutes)

Key Mfg. Process Parameters for Machine Learning Prediction

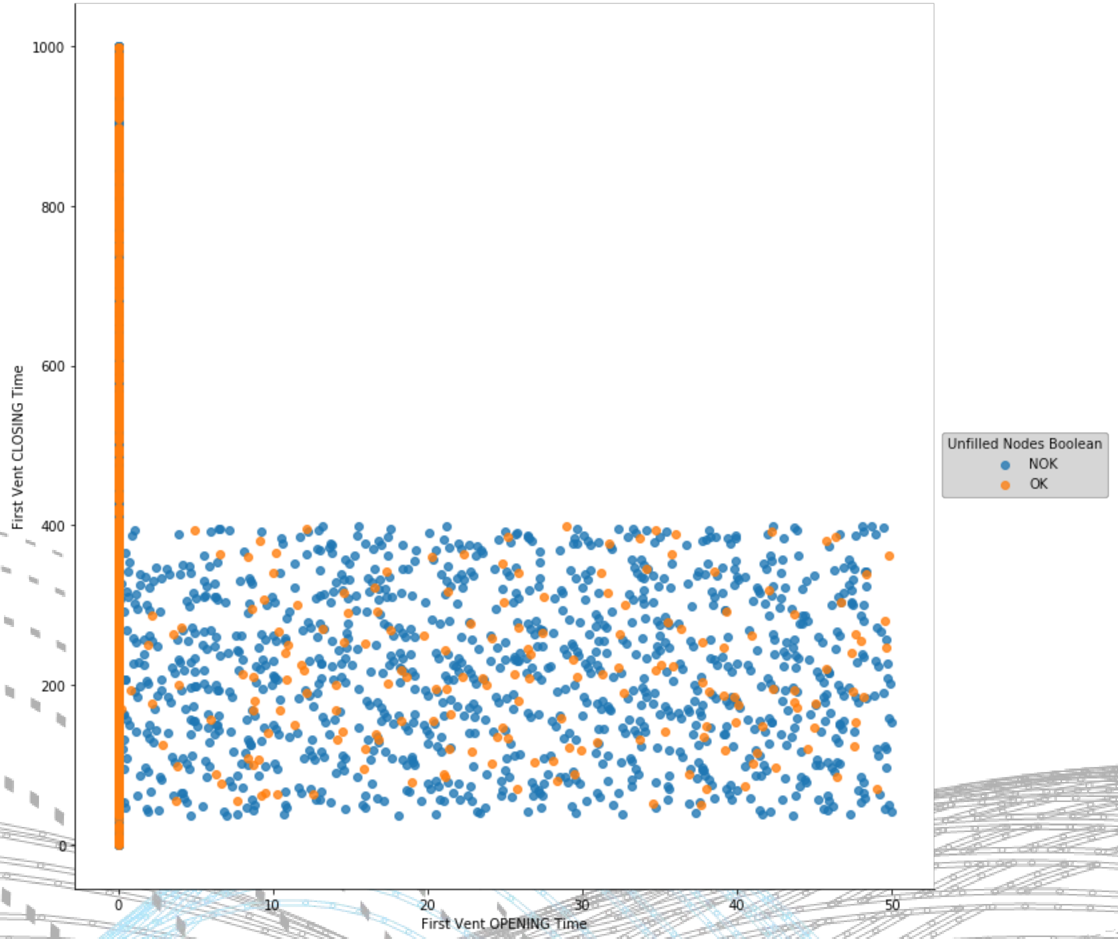
Mfg. Process Parameters



Mfg. Process Parameter Importance

Manufacturing Process → Problem Formulation → Input Data Exploration → Output Data Exploration → Machine Learning Dev → Prediction KPIs → Mfg. Process Insights

Key Mfg. Process Parameter#1 :
First Vent Timings (TCV1)

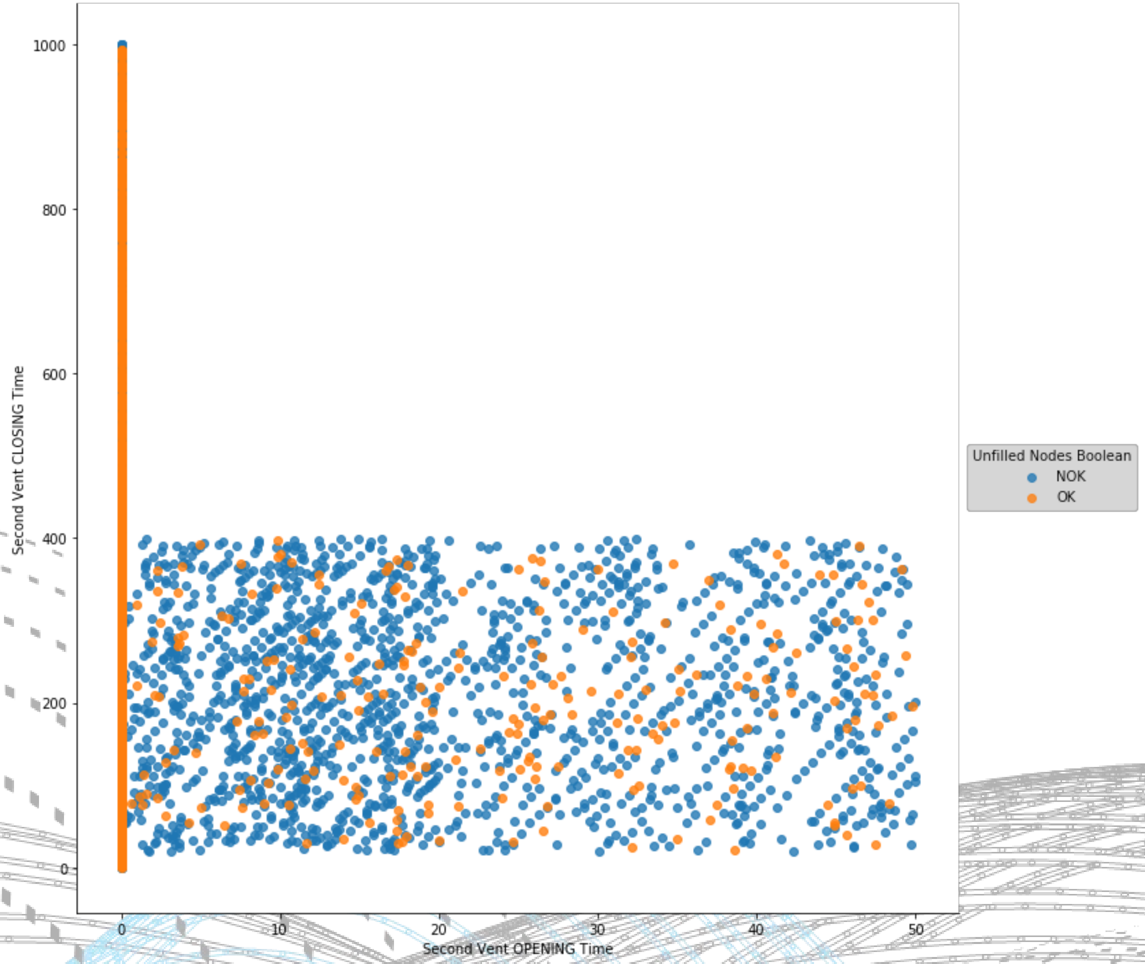


Insight

Opening the first vent (TOV1) at t=0 has a strong influence on improving the resin coverage

Manufacturing Process | Problem Formulation | Input Data Exploration | Output Data Exploration | Machine Learning Dev | Prediction KPIs | Mfg. Process Insights

Key Mfg. Process Parameter#2 :
Second Vent Opening & Closing Timings

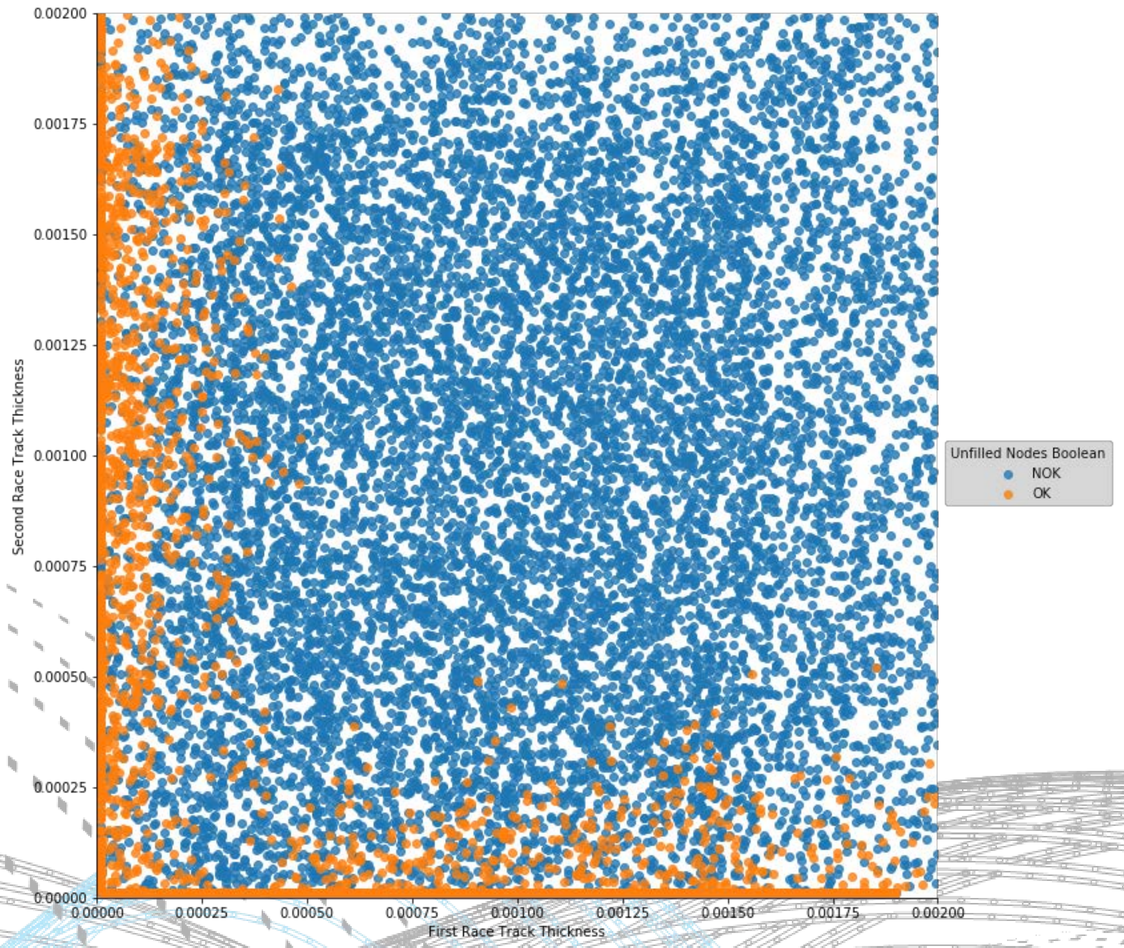


Insight

Opening the second vent (TOV2) at t=0 has a strong influence on improving the resin coverage

Manufacturing Process → Problem Formulation → Input Data Exploration → Output Data Exploration → Machine Learning Dev → Prediction KPIs → Mfg. Process Insights

Key Mfg. Process Parameter#3 :
Race Track Thickness Tolerance Band



Insight

Lower values for RT1T and RT2T has strong influence on improving the resin coverage

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CFMS
Bristol and Bath Science Park //
Dirac Crescent // Emersons Green //
Bristol // BS16 7FR

w: www.cfms.org.uk
e: info@cfms.org.uk
t: 0117 906 1100