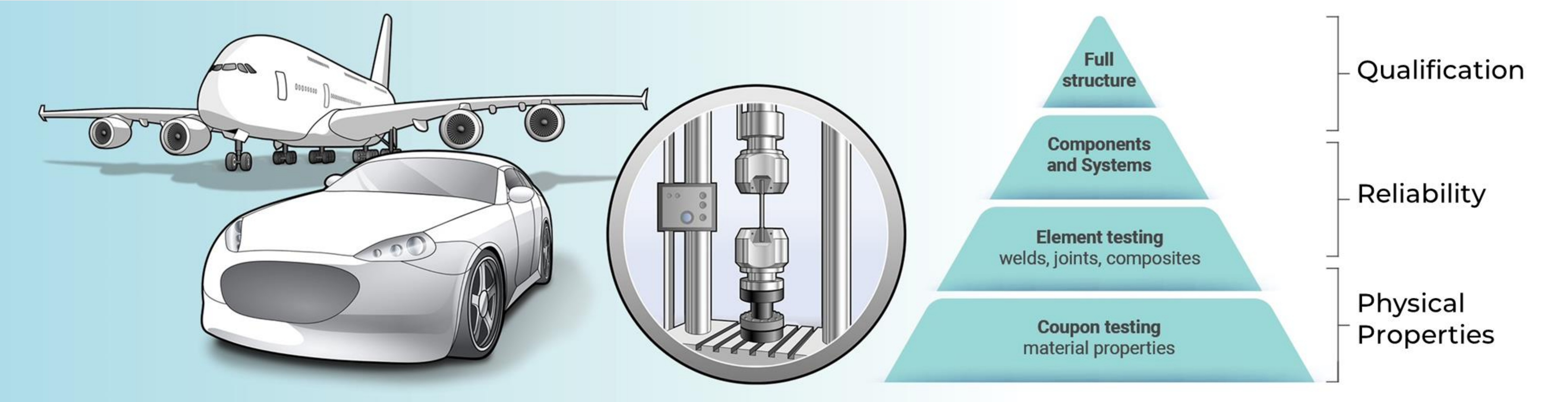

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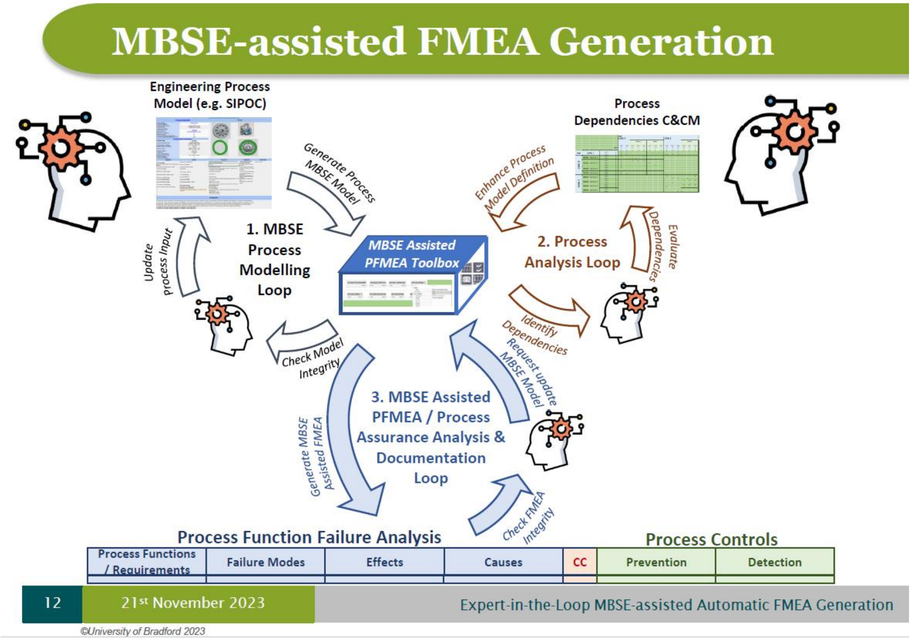


- **Placing the Expert in-the-Loop: Framework for MBSE-assisted FMEA Generation**

Prof. Felician Campean,
University of Bradford

Placing the Expert in-the-Loop: Framework for MBSE-assisted FMEA Generation

Abstract

- While significant progress has been made with the development and adoption of computer modelling and simulation tools to assist with the systems design, many of the analysis methods, in particular those focussed on robustness and reliability for the design and process assurance, including the FMEA, remain expert-centred and time and resource intensive. This talk outlines the development of an MBSE-assisted automatic FMEA generation tool, that places the expert in-the-loop, tasked with providing inputs and systematically reviewing the outcomes as generated system models. The approach emphasizes integration and traceability of requirements and critical characteristics across the levels of decomposition and analysis of the system.

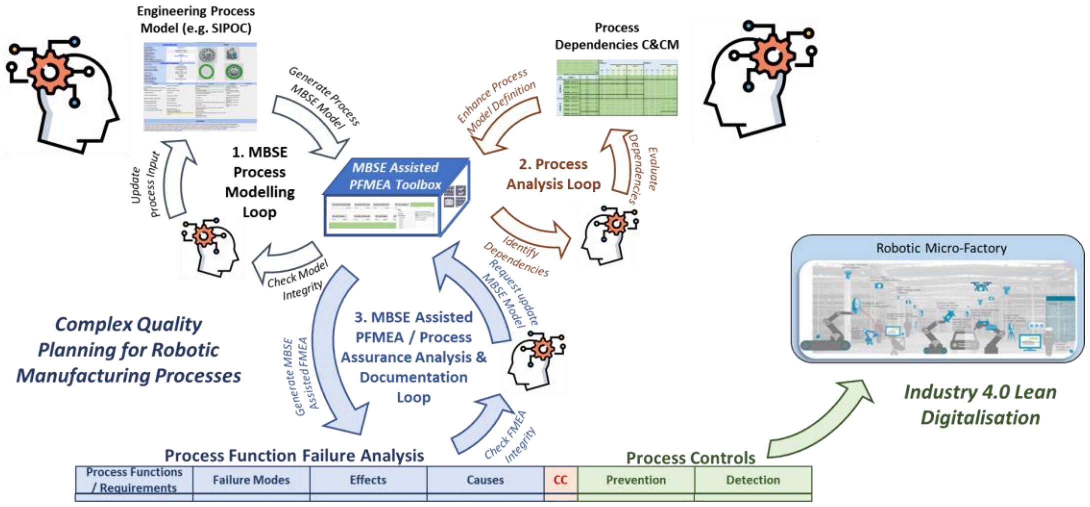
- A case study of a robotic manufacturing process design for an electric drive unit is used to illustrate the use of the tool in an industrial context. This illustrates the cascade of the critical characteristics across multiple levels of process and tooling design analysis, supporting the synthesis of robust process controls plans for an Industry 4.0 implementation. As well as discussing the effectiveness of the tool, a reflection on the interaction between the analyst / expert, the MBSE model and FMEA, facilitated by the tool is provided. The practical benefits are the robustness and integrity of the FMEA and other design assurance documentation, and their governance for future use.

Placing the Expert in-the-Loop: Framework for MBSE-assisted FMEA Generation

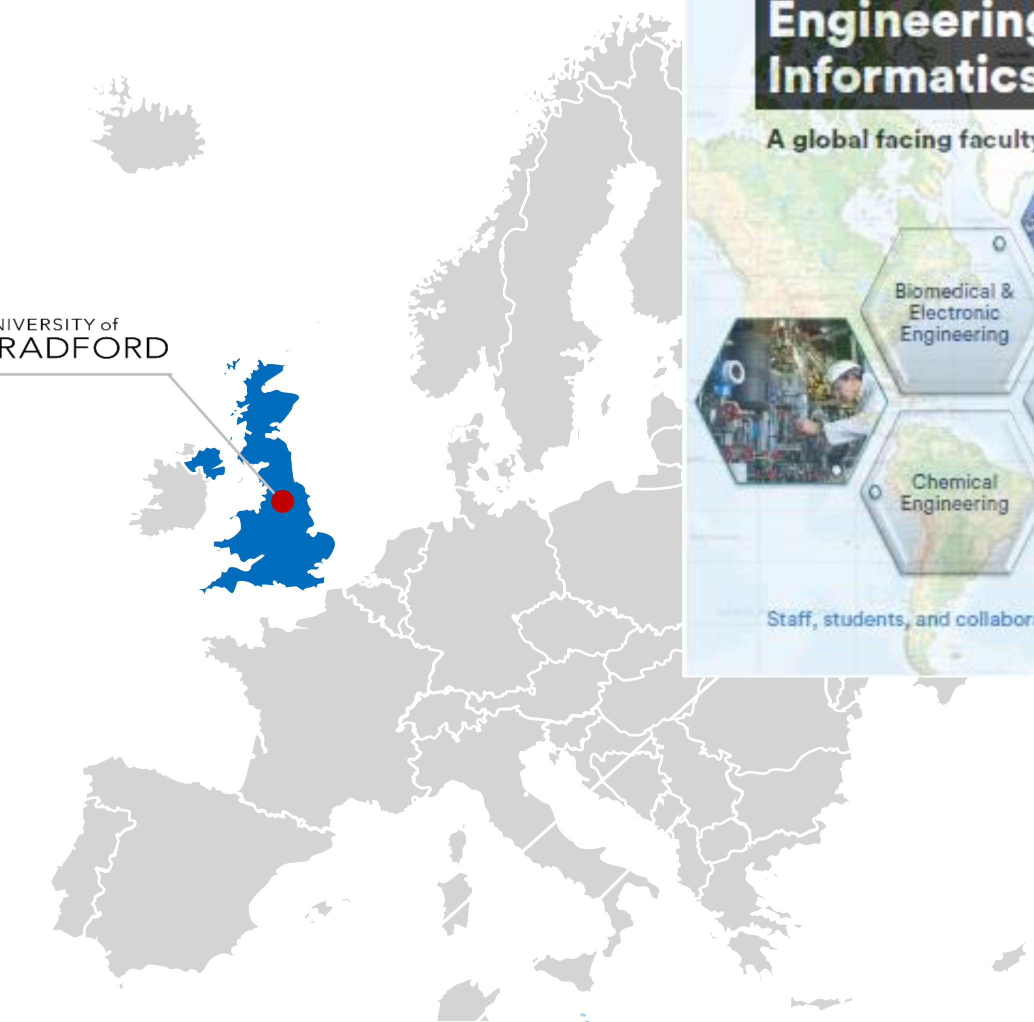
- About the presenter, Prof. Felician Campean, University of Bradford
  - Felician is a Professor in Reliability Engineering, Director of the Automotive Research Centre at the University of Bradford, and Associate Dean for Research & Innovation in the Faculty of Engineering and Digital Technologies. He holds a PhD in Reliability from Brunel University (1998) and a Mechanical / Manufacturing Engineering Degree from Transilvania University (1990).
  - His research interests revolve around the development of methods and tools to support design for performance, reliability and robustness in the product development of automotive and aerospace complex systems. This includes model-based methods for systems engineering, reliability, robustness and resilience analysis, AI big data analytics methods for intelligent systems lifecycle management, multi-disciplinary design optimization, modelling complex manufacturing and product development processes. He has an extensive track record of working with industry on collaborative research – both fundamental and applied, as well as effective knowledge transfer, with strong evidence of impact to industry.

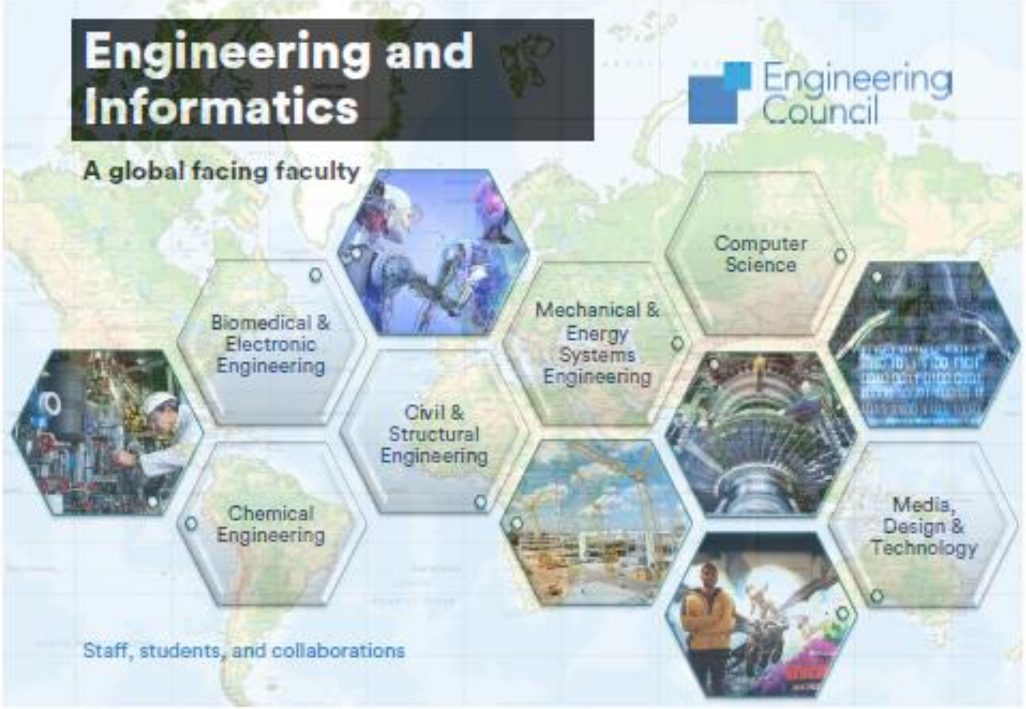
Placing the Expert in-the-Loop: Framework for MBSE-assisted Automatic FMEA Generation

Felician Campean
Aleks Korsunovs
Aleks Doikin
University of Bradford, UK



University of Bradford





United Nations Educational, Scientific and Cultural Organization

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ALBERT albert+ sustainable production

creative skillset

bcs The Chartered Institute for IT

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ice Institution of Civil Engineers

Institution of MECHANICAL ENGINEERS

IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

IET The Institution of Engineering and Technology

NHS Health Education England

Automotive Research Centre

BEQIC

Bradford Engineering Quality Improvement Centre

- Launched in 1995 – in partnership with Ford
- Enduring collaboration with the Automotive Industry

Research focus:
- *Reliability*; product development; systems engineering; "Failure Mode Avoidance"

Advanced Automotive Analytics

- Launched in 2016 – in partnership with JLR
- Cross-disciplinary collaboration ARC – Computer Science

Research focus:
- ML and AI applied to automotive and transportation problems, CPS & Industry 4.0

Automotive Systems Reliability Engineering

Brakes Research Centre

- Launched in 2010 – as Brakes Research Centre
- Strong track record of expertise in brakes

Research focus:
- Brakes Noise, Vibration & Harshness
- USPs: Unique Brakes NVH expertise and Testing Facilities; BRV Course.

Engine & Powertrain Research Laboratory

- Launched in 2010 – as Hyper-C (£2m development)
- 2 transient dynos, including 500KW regen dyno
- Emissions capability – Particle counter

Research focus:
- Powertrain modelling & Optimisation

Tribology Research Laboratory

Research focus:
- Engine tribology
- Lubricants

Materials & Surface Engineering Lab

Research focus:
- Surface coating;
- Joining & welding.
- Corrosion

Acoustics Research Laboratory

Research focus:
- Acoustic materials characterisation;
- New materials with acoustic properties

Bradford Engineering Quality Improvement Centre

BEQIC

Bradford Engineering Quality Improvement Centre

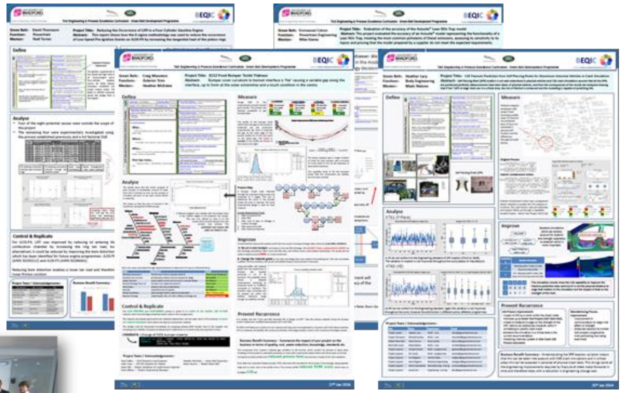
- Launched in 1995
- Enduring collaboration with the Automotive & Manufacturing Industries

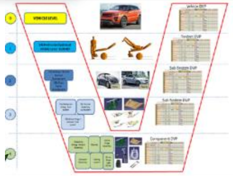
Research / Knowledge Exchange focus:
- Reliability & Robustness / “Failure Mode Avoidance”
- Process / Productivity Improvement
- Product Development
- Systems Engineering
- Multidisciplinary Design Optimisation

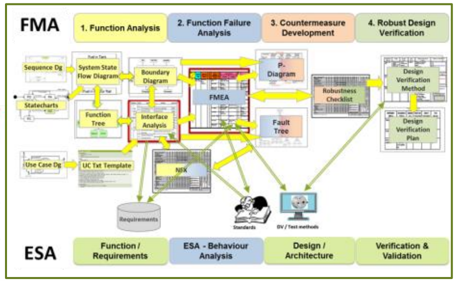
- Skills development

RIGHT FIRST TIME SEED

SHIFT LEFT Failure Mode Avoidance







Advanced Automotive Analytics Laboratory

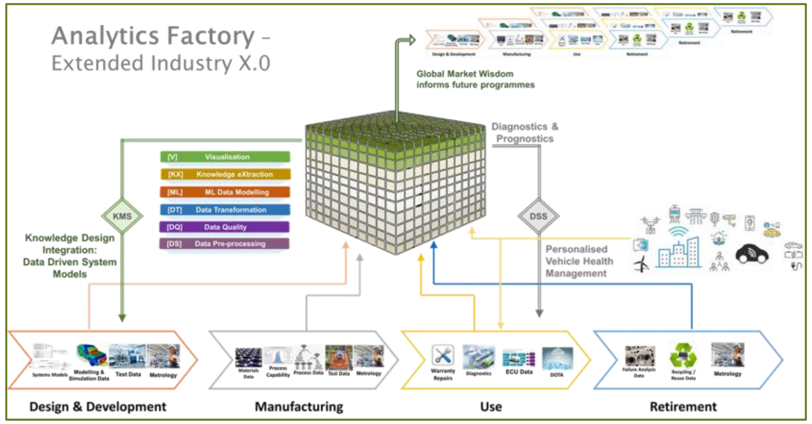
Advanced Automotive Analytics

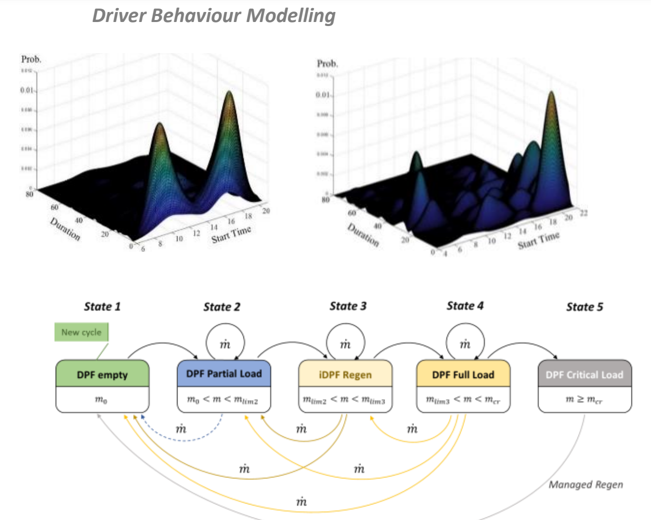
- Launched in 2016 Interdisciplinary collaboration

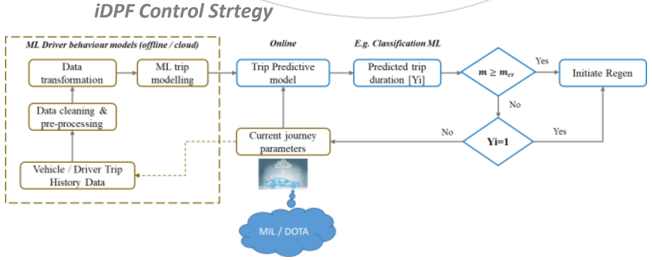
Research / Knowledge Exchange focus:

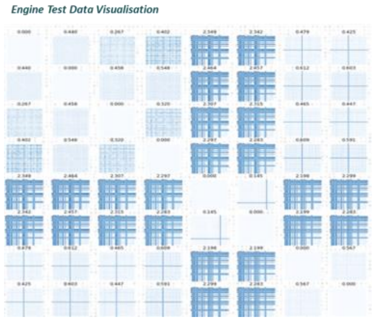
- Intelligent Systems Health Management, CPS & Industry-X.0
- Robustness & Safety of embedded AI
- Augmented intelligence for design & manufacturing
- Resilience & trust of autonomous systems
- Data centric life-cycle optimisation

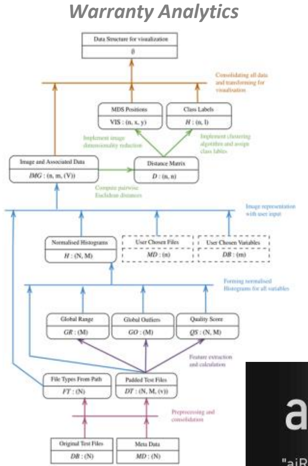
- Skills development - SAFI







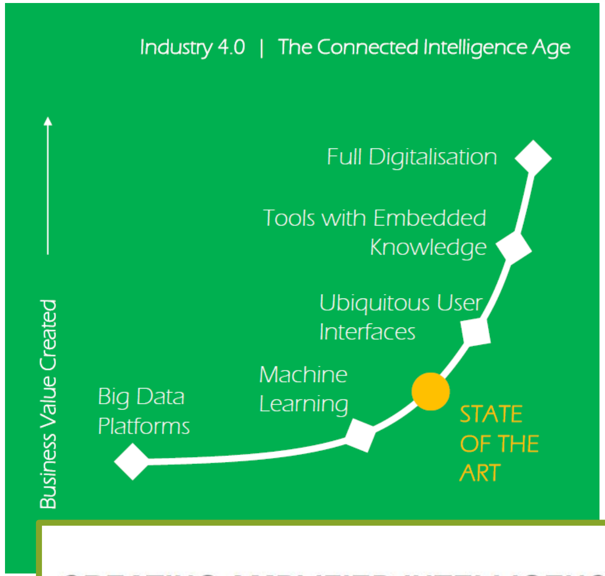


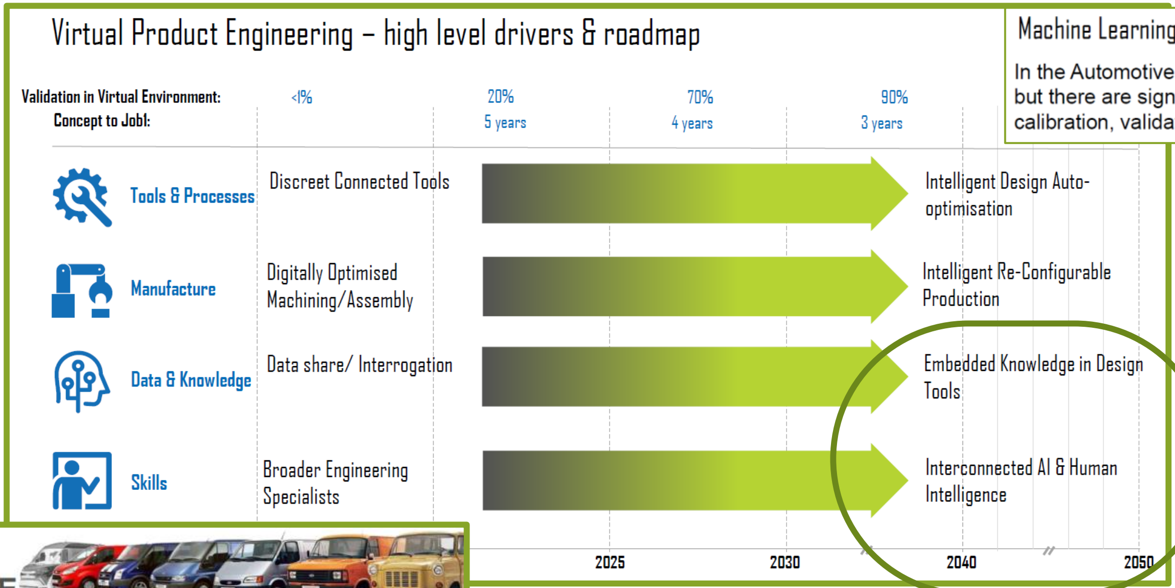


UNIVERSITY of BRADFORD

IDE INSTITUTE of DIGITAL ENGINEERING

Motivation: Automotive Council Digitalisation Roadmap 2050

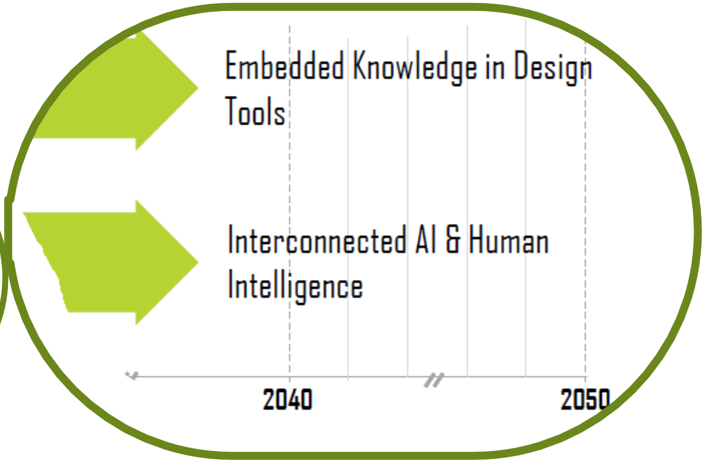


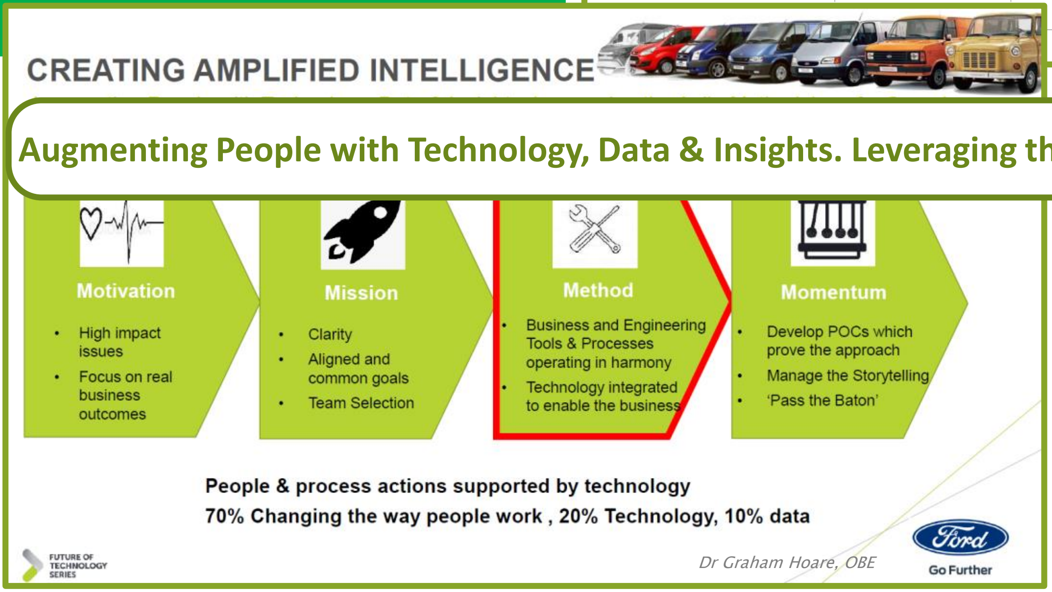


Machine Learning & AI in Product design and development

In the Automotive sector, machine learning and AI are mostly associated with automated driving but there are significant opportunities to employ these techniques in design, development, calibration, validation & manufacturing processes

Prof Neville Jackson, FREng





Augmenting People with Technology, Data & Insights. Leveraging the Agile Methodology for Speed

Research challenge: how do we evolve the PD methodologies, methods and tools to create ***amplified intelligence*** through ***interconnected AI & Human Intelligence***?

Motivation: R&D Opportunity

UK Research and Innovation

ADVANCED PROPULSION CENTRE UK

NextGenDrive R&D Project

- Aim: develop the prototype for a “robofactory” (robotic micro-factory) for EDUs
  - The robofactory is based on the “vertical integration” principles – the whole unit made and assembled in a fully robotised microfactory, leveraging I4.0 manufacturing & automation methods and local supply chains
  - EDU redesigned for robotic manufacturing
  - Full virtual integration of EDU and robotic manufacturing process design for early validation
- Research challenge for the UoB team: robotic manufacturing process design assurance and I4.0 smart lean digitalisation
  - Use the FMEA integrated with the manufacturing process design to derive a *sufficient* robust control plan and design the I4.0 implementation
- Research approach: MBSE modelling for robotic manufacturing process design with MBSE-Assisted Automatic FMEA Generation

MBSE-assisted Auto-FMEA Approach

FMEA Challenges

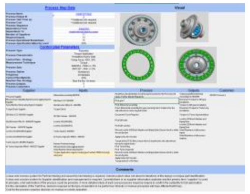
Human factors / effectiveness:
- Labour intensive / time consuming
- Error prone
- Difficult to update & interpret

Outcomes:
- Uncertain completeness and integrity of the analysis
- Unwieldy / not reflecting the recursive analysis at different levels

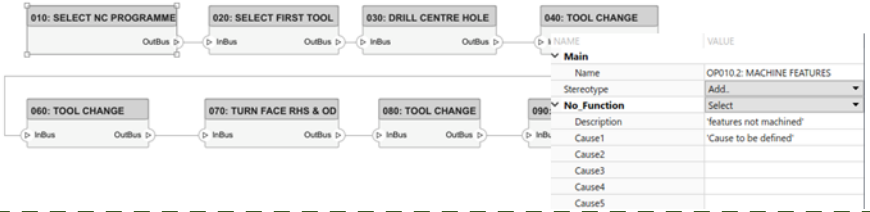
Integration with Process Design flow:
- FMEA not updated to reflect changes to design / model
- Lack of traceability between high level requirements and process controls

MBSE-assisted Auto-FMEA approach

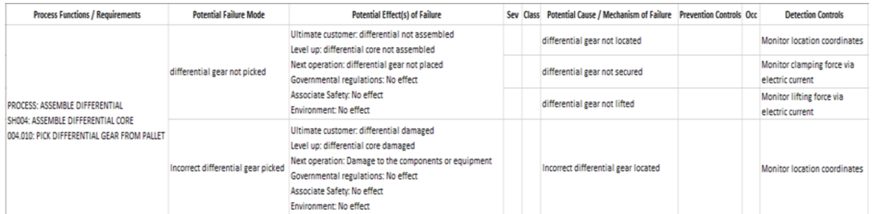
Engineering Process Model e.g. SIPOC



MBSE Model



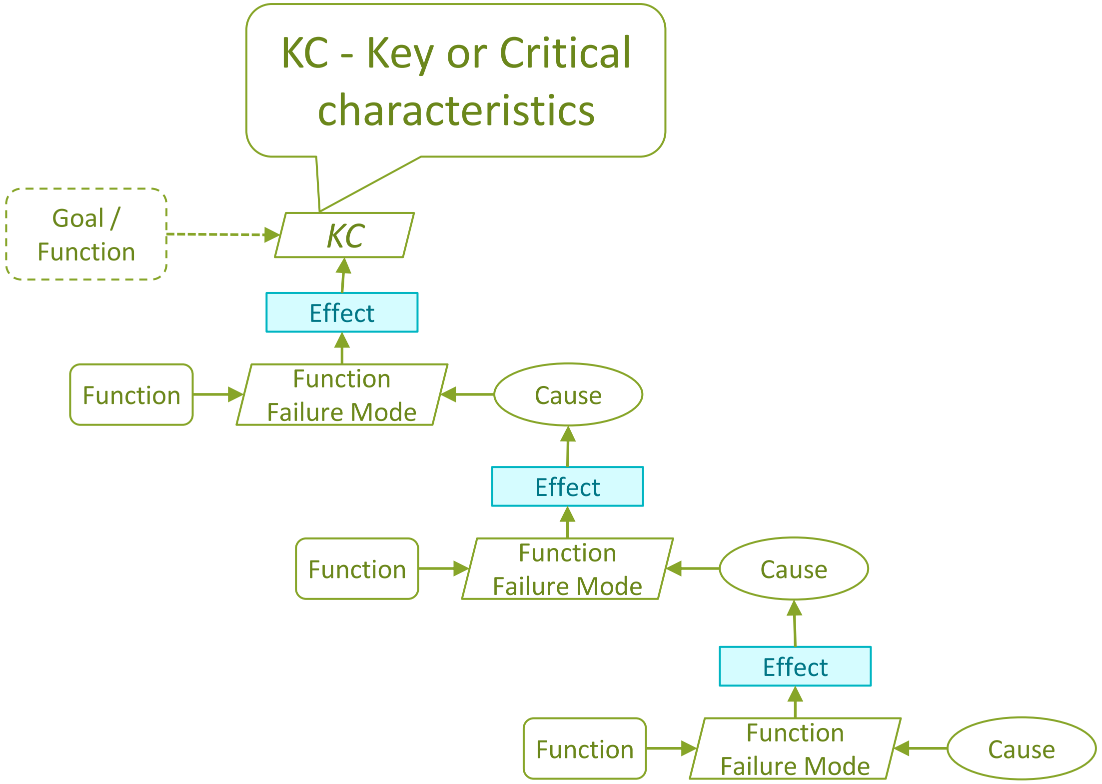
Generated PFMEA

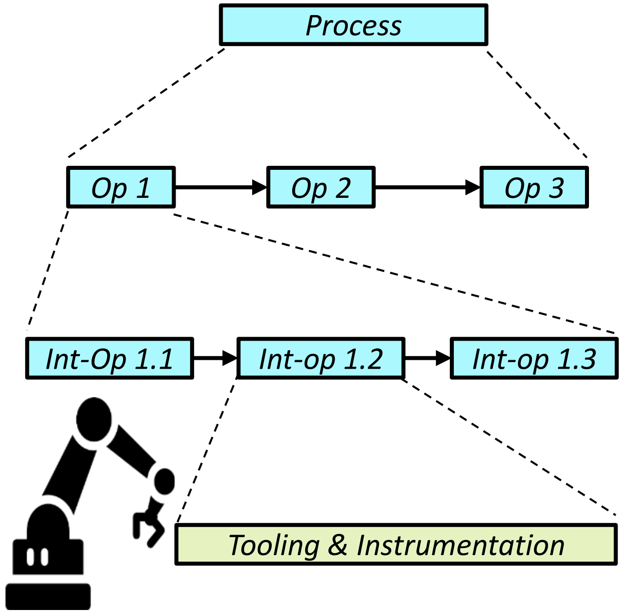


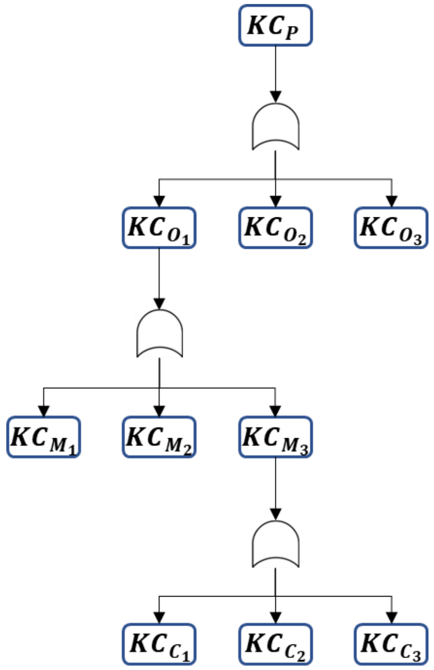
Process Functions / Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause / Mechanism of Failure	Prevention Controls	Occ	Detection Controls
PROCESS: ASSEMBLE DIFFERENTIAL SH004: ASSEMBLE DIFFERENTIAL CORE 004.010: PICK DIFFERENTIAL GEAR FROM PALLET	differential gear not picked	Ultimate customer: differential not assembled Level up: differential core not assembled Next operation: differential gear not placed Governmental regulations: No effect Associate Safety: No effect Environment: No effect			differential gear not located			Monitor location coordinates
					differential gear not secured			Monitor clamping force via electric current
					differential gear not lifted			Monitor lifting force via electric current
	Incorrect differential gear picked	Ultimate customer: differential damaged Level up: differential core damaged Next operation: Damage to the components or equipment Governmental regulations: No effect Associate Safety: No effect Environment: No effect			Incorrect differential gear located			Monitor location coordinates

- Initial technical challenges:
  1. Develop an “**X-ITL**” (Expert / Engineer in the Loop) approach to a comprehensive MBSE for manufacturing process design with integrated FMEA generation;
  2. Automate the traceability of key characteristics across the levels of process-as-a-system decomposition

Understanding the Systemic FMEA Reasoning

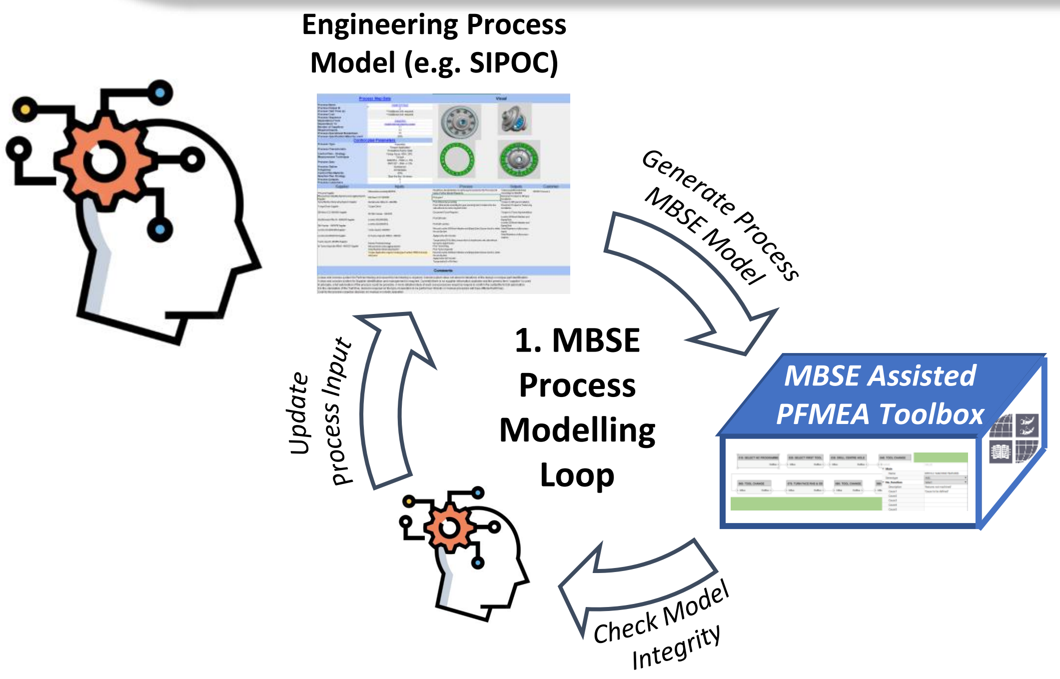


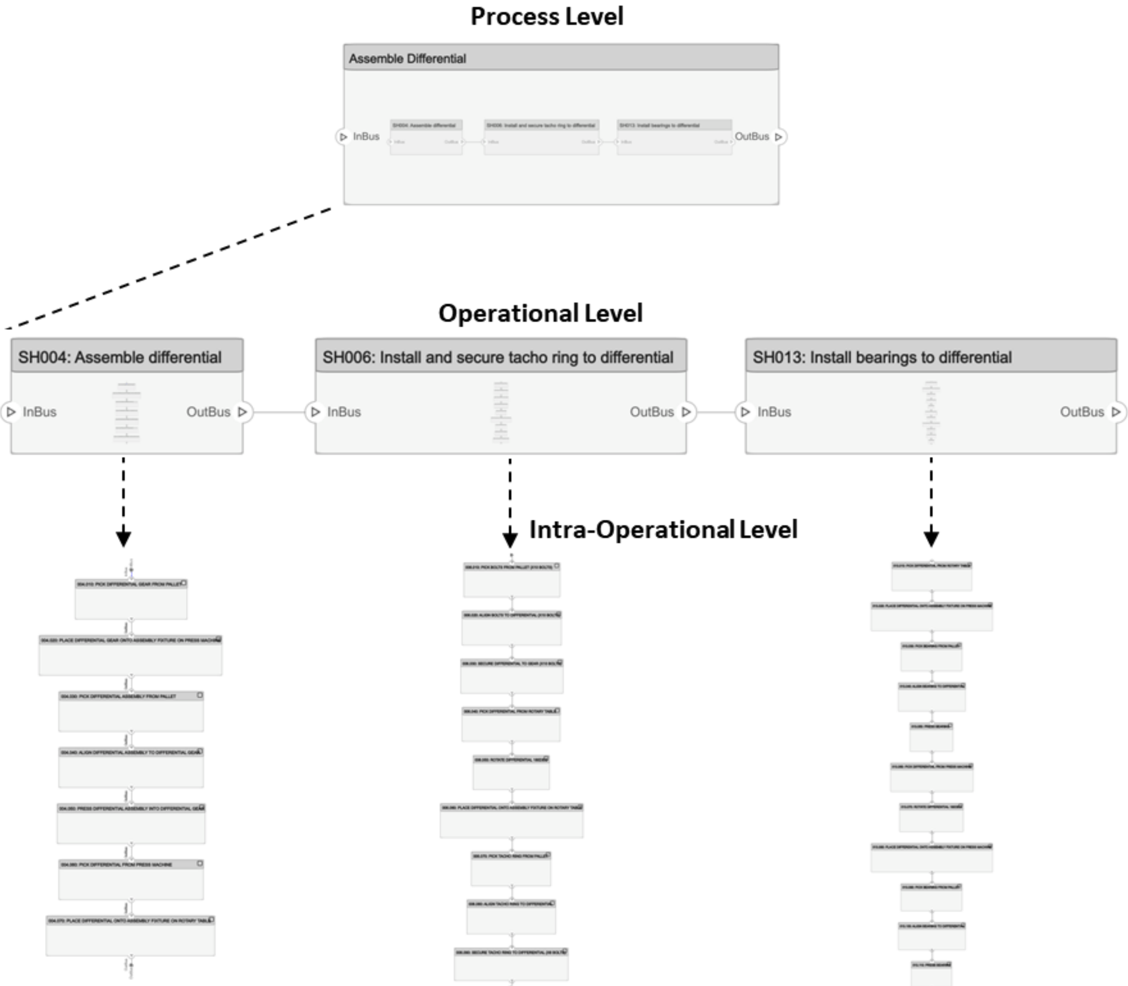




- Research / technical challenges:
  1. Develop an "**X-ITL**" (Expert / Engineer in the Loop) approach to a comprehensive MBSE for manufacturing process design with integrated FMEA generation;
  2. Automate the traceability of key characteristics across the levels of process-as-a-system decomposition

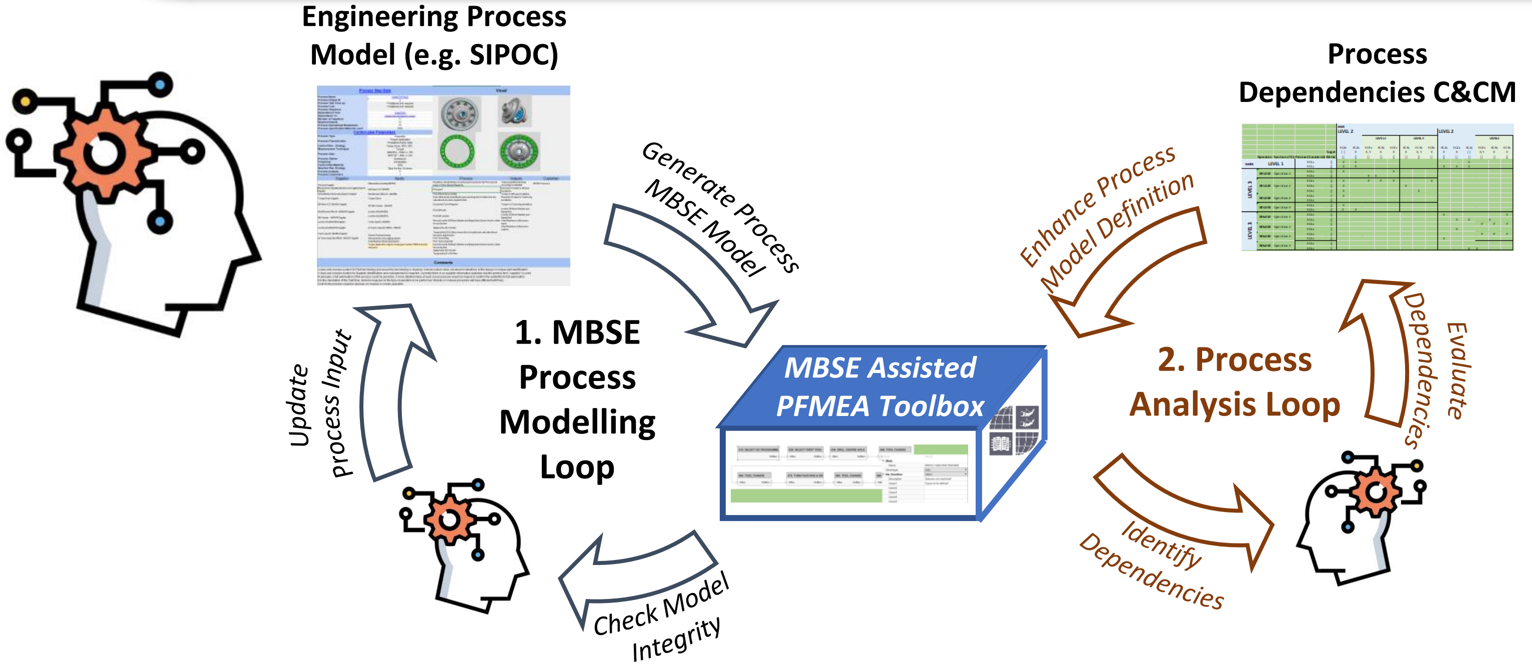
X-ITL MBSE Process Modelling



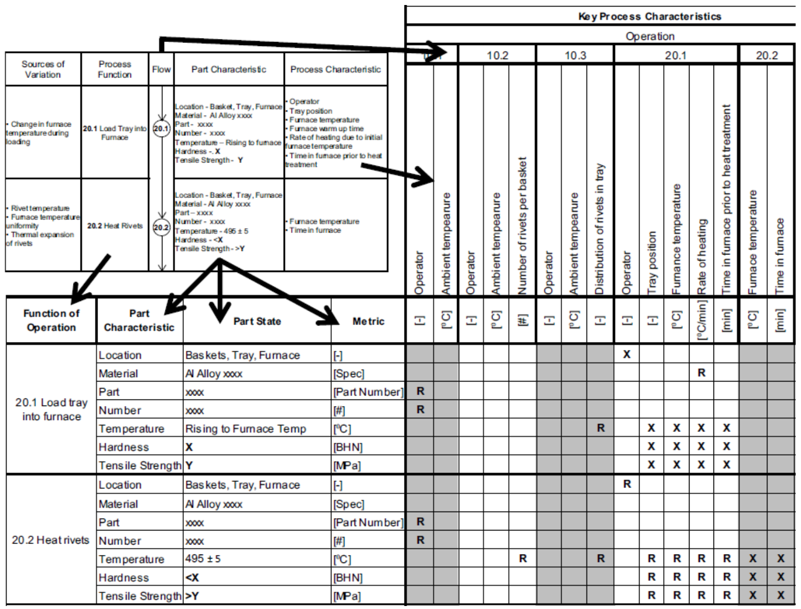


- The MBSE model is generated automatically from the Engineering Process Model generated by experts;
- If the expert / analyst is not happy with the model s/he will have to adjust the input;
- NB Reverse flow enabled – i.e. Engineering process model (SIPOC, IDEF, etc) can be generated from MBSE

X-ITL Process Analysis



We have developed and implemented the Ford[1] approach based Critical & Correlation Matrix (CCM) to characterise dependencies



				Key Process Characteristics														
				Operation														
				10.1		10.2			10.3			20.1					20.2	
				Operator	Ambient tempearure	Operator	Ambient tempearure	Number of rivets per basket	Operator	Ambient tempearure	Distribution of rivets in tray	Operator	Tray position	Furnance temperature	Rate of heating	Time in furnace prior to heat treatment	Furnace temperature	Time in furnace
Function of Operation	Part Characteristic	Part State	Metric	[-]	[ºC]	[-]	[ºC]	[#]	[-]	[ºC]	[-]	[-]	[-]	[ºC]	[ºC/min]	[min]	[ºC]	[min]
20.1 Load tray into furnace	Location	Baskets, Tray, Furnace	[-]									X						
	Material	Al Alloy xxxx	[Spec]												R			
	Part	xxxx	[Part Number]	R														
	Number	xxxx	[#]	R														
	Temperature	Rising to Furnace Temp	[ºC]								R		X	X	X	X		
	Hardness	X	[BHN]										X	X	X	X		
	Tensile Strength	Y	[MPa]										X	X	X	X		
20.2 Heat rivets	Location	Baskets, Tray, Furnace	[-]									R						
	Material	Al Alloy xxxx	[Spec]															
	Part	xxxx	[Part Number]	R														
	Number	xxxx	[#]	R														
	Temperature	495 ± 5	[ºC]					R			R		R	R	R	R	X	X
	Hardness	<X	[BHN]										R	R	R	R	X	X
	Tensile Strength	>Y	[MPa]										R	R	R	R	X	X

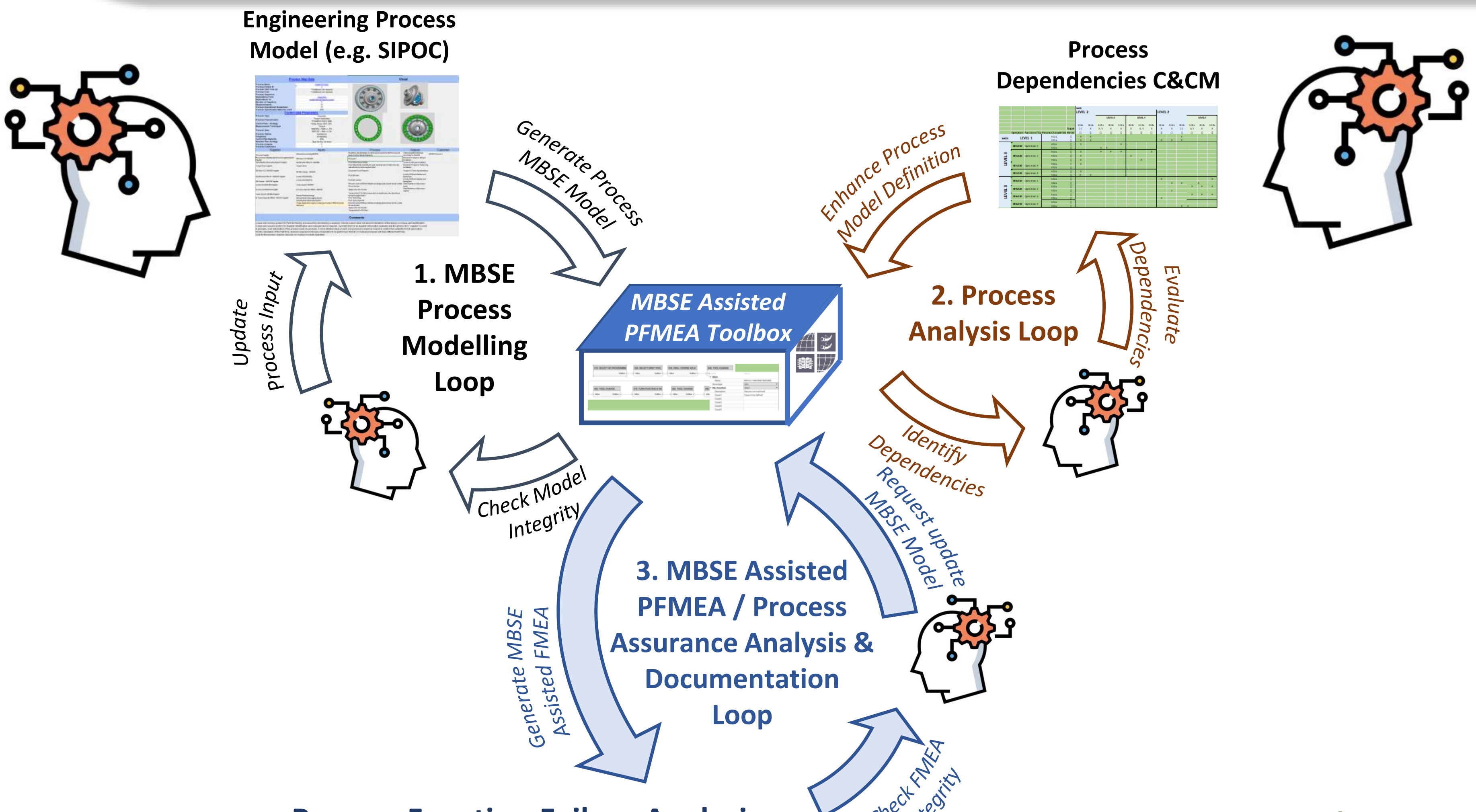
- The CCM data structure is quite complex as we need to capture both inter- and intra-level dependencies:
  - Inter-level dependencies – allocation of KCs to next level of decomposition;
  - Intra-level dependencies – propagation of KC flags within the same level where operations have functional dependencies

This is dependent on the process / solution – hence analysis is concurrent with process design

It also means a two-step process for the CCM – and FMEA

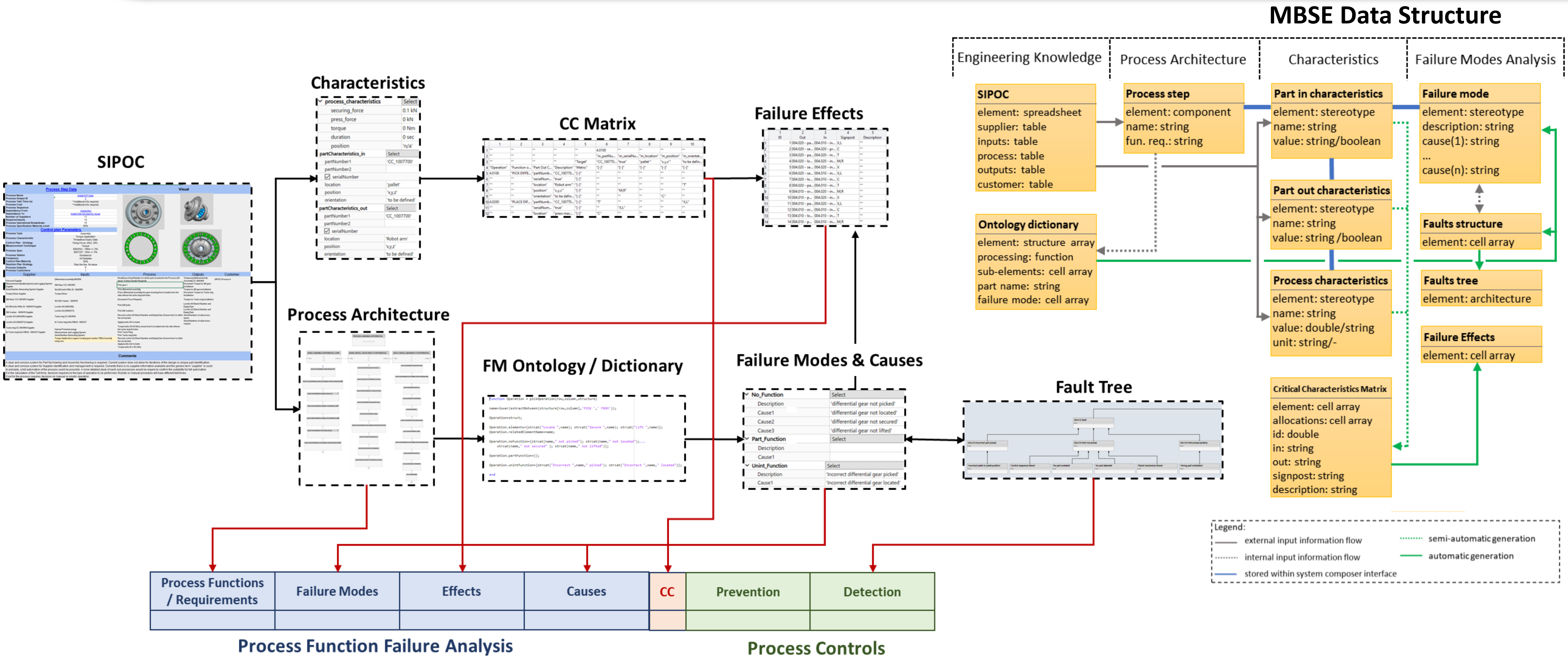
[1]*FMEA with Robustness Linkages, Ford Motor Company, 2004*

MBSE-assisted FMEA Generation

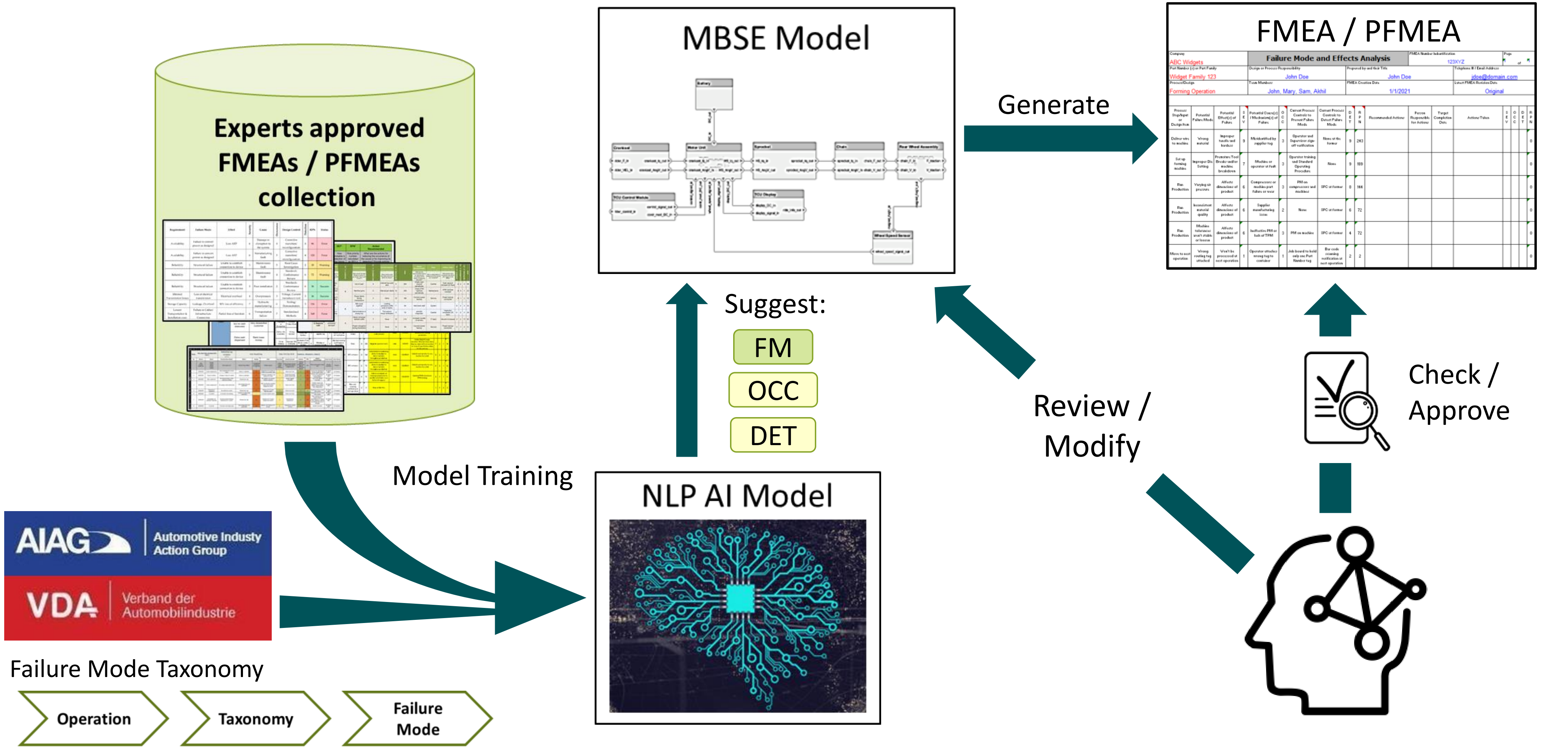


Process Function Failure Analysis					Process Controls	
Process Functions / Requirements	Failure Modes	Effects	Causes	CC	Prevention	Detection

MBSE-assisted FMEA Generation

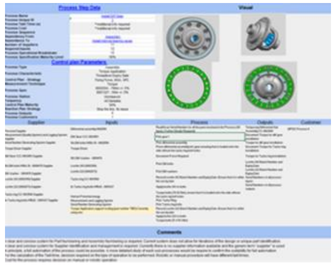


Intelligent Failure Modes Dictionary

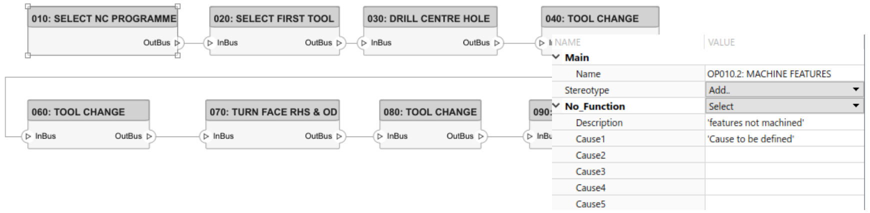


Example

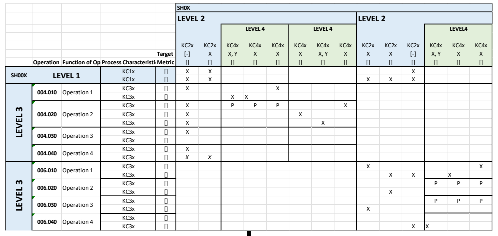
SIPOC

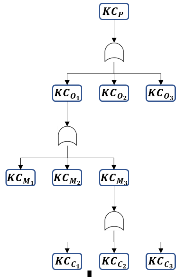


Process Flow MBSE Model



CC Matrix & Characteristics Cascade





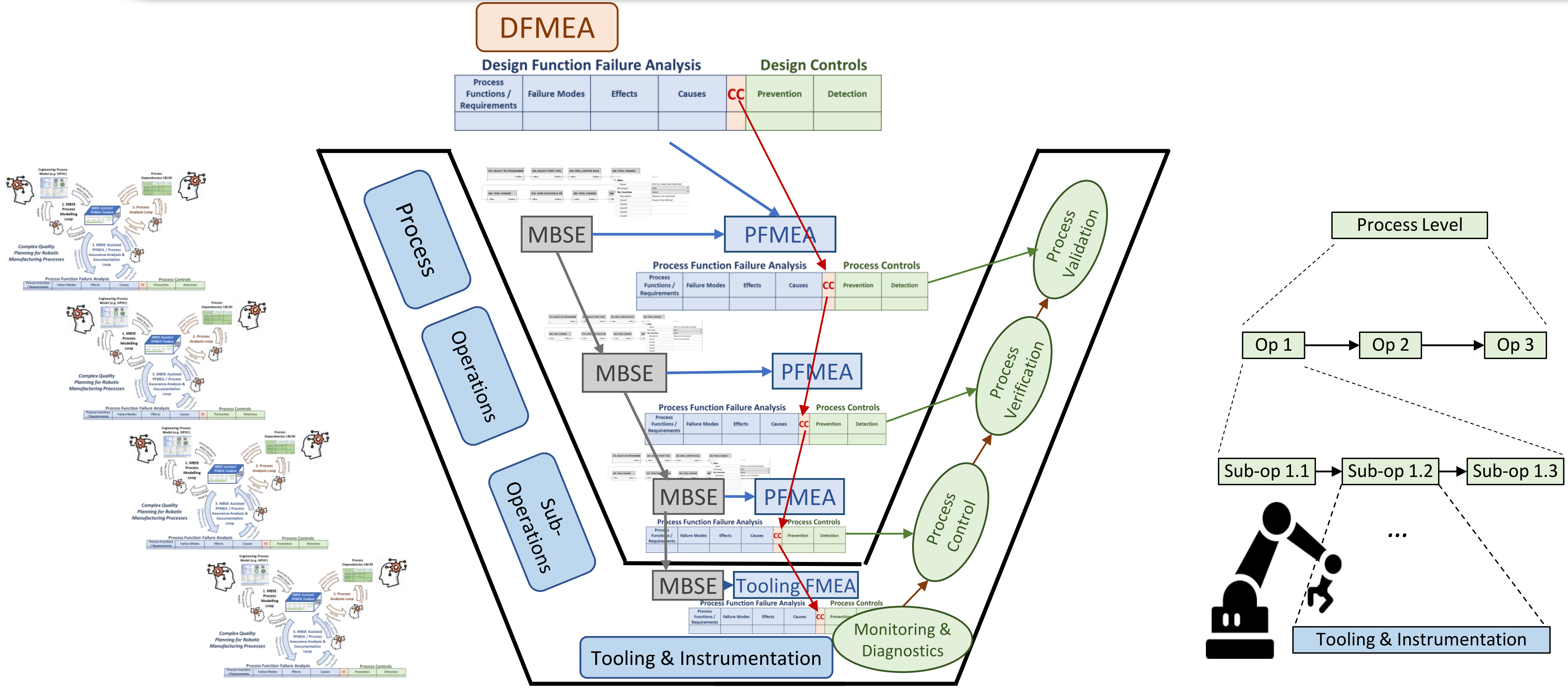
Automatic Generation of Process FMEA

Effects of failure mode are automatically suggested from the C&CM

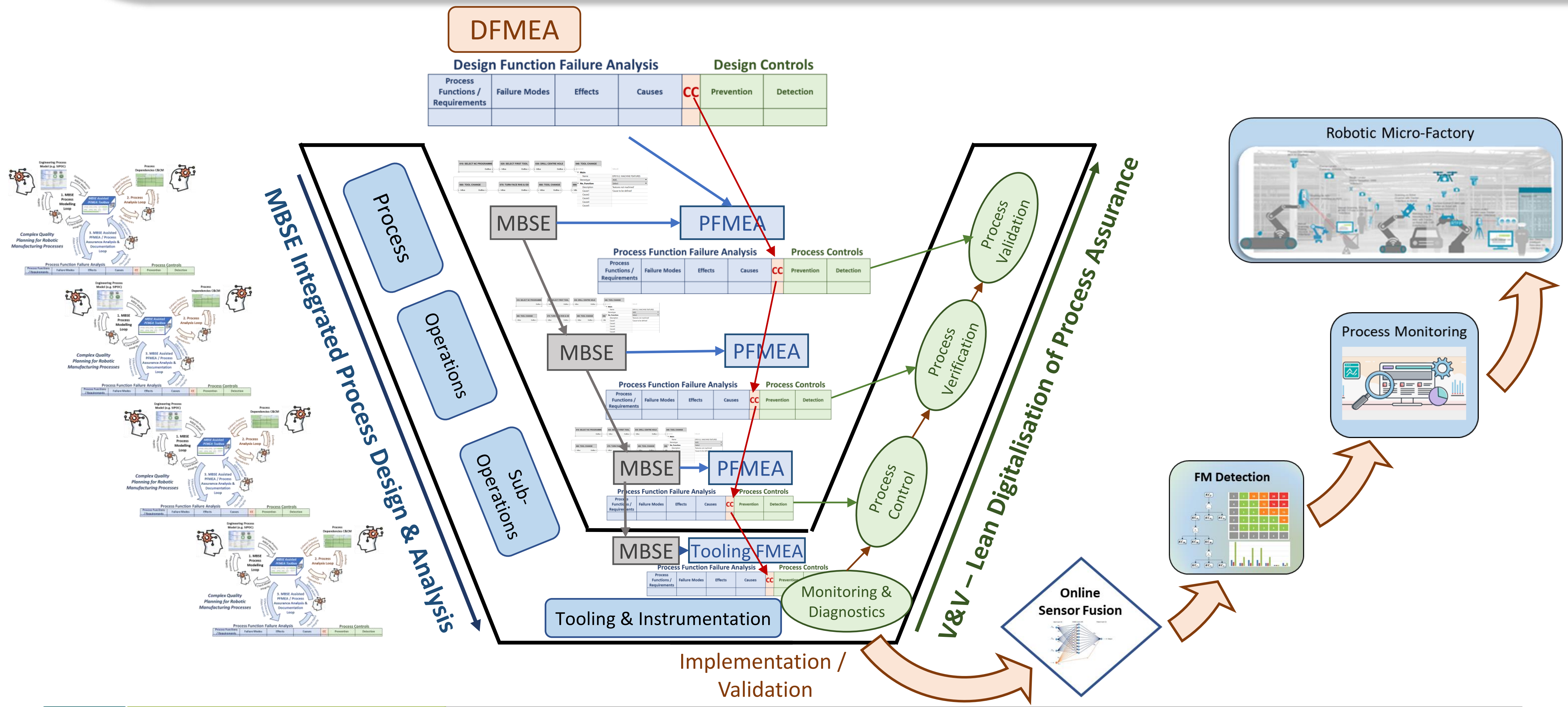
Severity automatically cascaded based on the traceability to DFMEA

Process Functions / Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	P… use / Mechanism of Failure	Prevention Controls	Occ	Detection Controls
PROCESS: ASSEMBLE DIFFERENTIAL CORE SH004: ASSEMBLE DIFFERENTIAL CORE 004.010: PICK DIFFERENTIAL GEAR FROM PALLET	differential gear not picked	Ultimate customer: effect on operation SH004, Part Geometry (5) Level Up: effect on operation SH004, Part Geometry (5) Next operation: effect on operation 004.020, Path Availability (5) Governmental regulations: No effect Associate Safety: No effect Environment: No effect	5		differential gear not located			Monitor Location via Location Coordinates
					differential gear not secured			Monitor Clamping Force via Electric Current
					differential gear not lifted			Monitor Lifting Force via Electric Current
	Incorrect differential gear picked	Ultimate customer: effect on operation SH004, Part Geometry (5) Level Up: effect on operation SH004, Part Geometry (5) Next operation: effect on operation 004.020, Path Availability (5) Governmental regulations: No effect Associate Safety: No effect Environment: No effect	5		Incorrect differential gear located			Monitor Location via Location Coordinates

Integrated MBSE Robofactory Process Design



Integrated MBSE Robofactory Process Design



Discussion & Conclusions

- Successful proof of concept for the next generation design tools that deliver amplified intelligence through interconnected AI & Human Intelligence – i.e. “Expert in the Loop”
    - Current state: alpha prototype developed and validated with a subsystem of the EDU robotic manufacturing process
        - » System Design / DFMEA in progress

- Current work:
    - Develop an AI ontology for function failure representation, with an extended taxonomy for failure modes to support integrated MBSE-assisted FMEAs for intelligent physical systems – equipped with embedded AI
    - Develop intelligent data-driven FMEAs – i.e. automatic build of the MBSE-assisted FMEA from real world failure data (e.g. warranty data)

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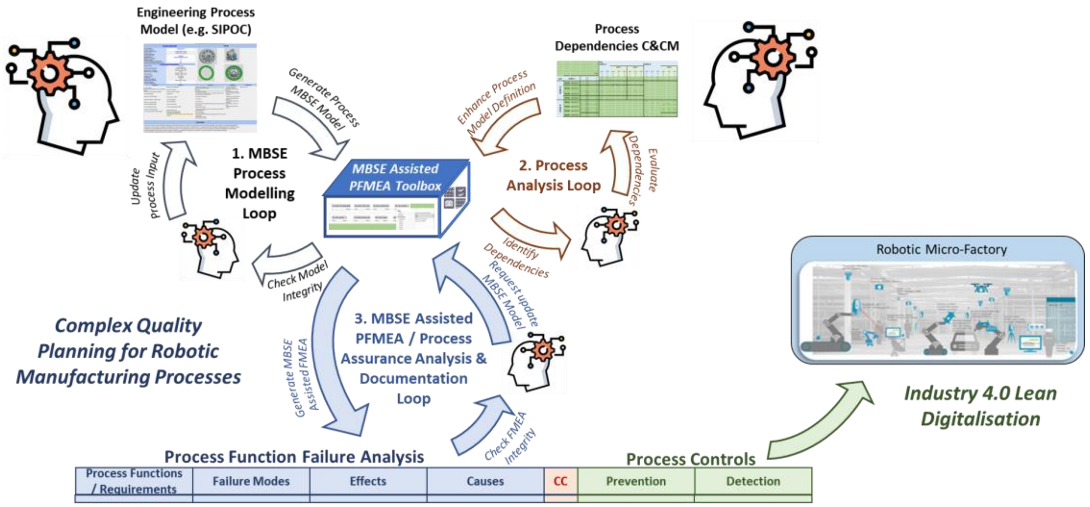
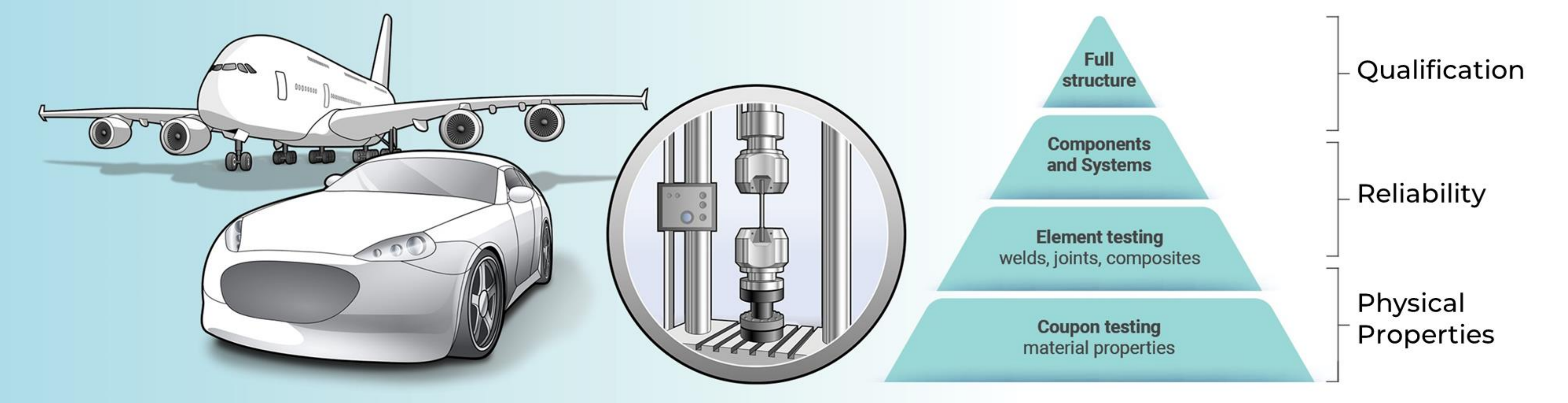
Placing the Expert in-the-Loop: Framework for MBSE-assisted Automatic FMEA Generation



Thank You!

F.Campean@Bradford.ac.uk



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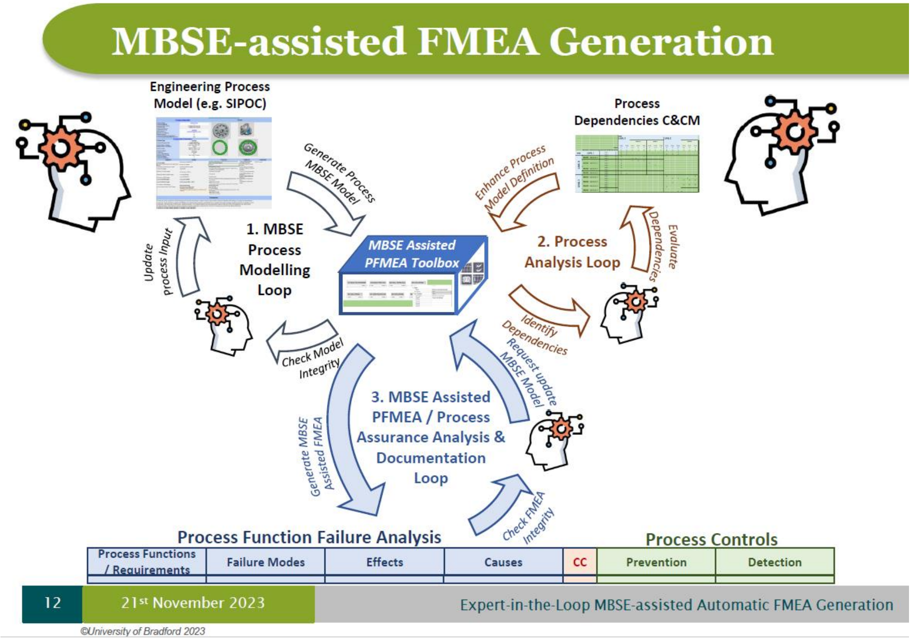

- **Placing the Expert in-the-Loop: Framework for MBSE-assisted FMEA Generation**

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  University of Bradford