

# TRUSTWORTHY AI FRAMEWORK

A COMPREHENSIVE REVIEW OF AI STANDARDS POLICIES AND  
A PRACTICAL GUIDELINE TO THEIR APPLICATION IN MANUFACTURING



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# Executive Summary

The progress of Artificial Intelligence (AI) in recent years has transformed the public perception of AI from being science fiction and researched by top universities to a tool for present day applications. While AI and Machine Learning technology has rapidly developed, the implementation and adoption of these technologies in the manufacturing sector has been slow. One of the reasons why this has occurred has been the lack of Trust in AI systems and clear understanding of standards and policies. Trustworthy AI looks to establish this trust through a series of principles and practices that provide confidence that an AI system is secure, fair, transparent, accountable, and robust. AI assurance techniques mean to provide a framework for manufacturing stakeholders to assess trustworthiness in the development and deployment of their AI systems.

Furthermore, while there are numerous AI standards and policies available, these policies are often difficult to extract relevant guidance making them impractical for AI developers. This information inundation makes it challenging for manufacturing stakeholders to discern which standards and policies are most relevant to their operations and which ones they should adhere to. As a result,

there is a pressing need for more comprehensive frameworks that offer clear, actionable recommendations for integrating AI technologies into manufacturing processes while ensuring trustworthiness and compliance with industry standards. Without such guidance, the potential benefits of AI in manufacturing may remain unrealised, hampering its widespread adoption and optimisation.

This paper provides a comprehensive view of current AI standards and frameworks and the current usage of these assurance techniques in generating trust in AI systems. The overall findings from the paper suggest that while current standards and frameworks demonstrate some of the assurance techniques, there is still yet to exist a holistic approach to these assurance techniques in AI systems. The recommendations for what are next in this area is to create an approach using the principles and practices and ensuring that this approach can be applied across a wider manufacturing sector.

The detailed framework is available as supplementary material upon request. To obtain your copy of the Trustworthy AI framework, please send your request to [aigovernance@the-mtc.org](mailto:aigovernance@the-mtc.org).

# Introduction

Artificial Intelligence (AI) has advanced rapidly in recent years as different developments have improved its capability and function, such as new and improved learning methods combined with the increased availability of large datasets for training and self-learning. The emergence of ChatGPT and other publicly available generative AI systems has made AI a very popular topic of discussion in the public sphere and garnered increased interest in many industry sectors as organisations look to harness the benefits of AI. However, AI has been employed in industry for some time in various forms with many identifying the potential advantages for different sectors and applications early on.

Manufacturing has been seen as an industry prime for AI implementation, with potential for significant value to be added across the whole value chain in a variety of ways. While AI is not a new concept, with much research and

work invested into this area, the wider adoption of AI within manufacturing sector is still in relatively early stages. In a survey conducted on UK businesses <sup>[1]</sup>, just over 15% of the manufacturing business respondents indicated they have currently adopted AI, with roughly a further 13% intending to use it. A PwC global survey found just 9% of the 1,155 manufacturing executives surveyed had implemented AI into their processes to improve operational decision making <sup>[2]</sup>. These numbers are likely higher as of 2024, however the information highlights the fact that the manufacturing sector is not a leading AI adopter despite the identified benefits.

Although there are many opportunities and potential benefits to AI deployment for manufacturing, the industry remains slow to adopt the technology. Figure 1 shows the general challenges to the industrialisation of AI technologies from feedback of various vendors and end users across different sectors in manufacturing.

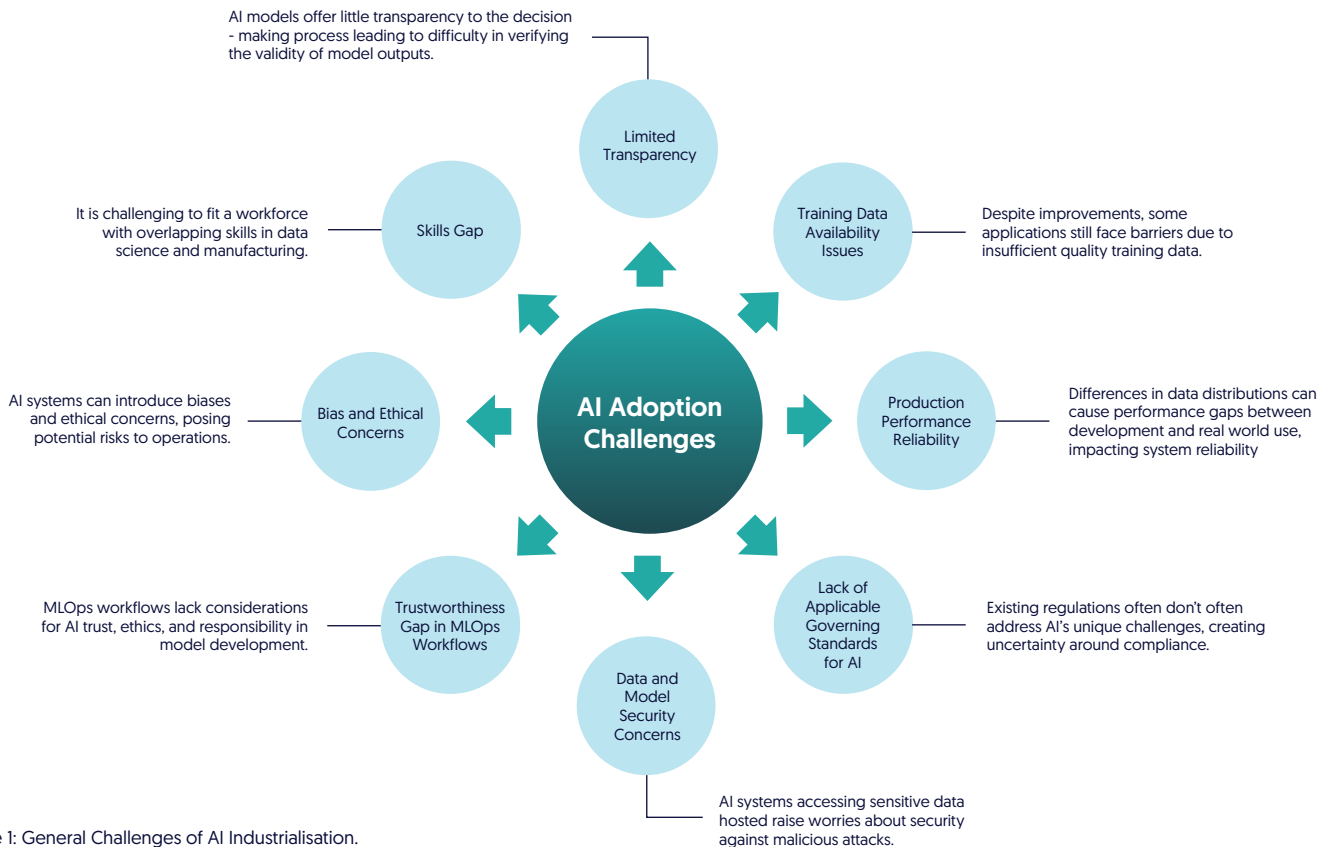


Figure 1: General Challenges of AI Industrialisation.



As seen in Figure 1 the concerns of the manufacturing sector stretch across a wide range of factors; from performance to ethical concerns, to a lack of transparency in decision making processes. Some of these challenges can be overcome by following Trustworthy AI principles which look at establishing guidance on development and deployment of AI models. There have been large amounts of research on this topic, including published papers and governmental guidance due to the rapid and continuous development of AI technology. However, it remains a poorly understood topic for the manufacturing industry with a lack of practical implementation of these principles through official frameworks.

Numerous national and international initiatives are aimed at addressing the topic of trustworthy AI, including the AI summit at Bletchley Park <sup>[3]</sup> and the EU AI act <sup>[4]</sup>. This has

encouraged an increased work effort on the standardisation of AI development and deployment, helping society make big strides in understanding AI best practices. Yet, with the large number of standards released in recent years, it is making it difficult for industry to navigate the plethora of frameworks available. This paper provides a structured guide to identifying the correct directives for the different themes within trustworthy AI.

This paper will further address the problem of implementing trustworthy AI for critical manufacturing application with an exploration of frameworks, standards, and reports covering the topic of trustworthy AI.







# Trustworthy AI

Before delving into trustworthy AI, it's essential to establish a clear definition of AI itself. The MTC defines AI as leveraging data, algorithms, and machines to simulate intelligence, enabling them to perform tasks that require cognition such as decision making and problem solving. The noun Intelligence refers to the cognitive ability to perceive knowledge or information which is then applied to carry out functional tasks.

Implementation of AI can range from being used in computer vision systems to identify for quality assurance in manufacturing lines, to using multiple AI models in which predictive maintenance combined with a large language model can be used to inform manufacturers about problems and possible solutions in more human-centric way. In addition, AI's impact on manufacturing extends to a wide array of scenarios, such as revolutionising inventory management through real-time demand forecasting or facilitating personalised product customisation through adaptive production processes.

By leveraging AI in these diverse capacities, manufacturers can achieve unprecedented levels of agility, responsiveness, and customer satisfaction, ultimately driving competitive advantage in the rapidly evolving marketplace. Furthermore, AI finds application in various facets of manufacturing, spanning from optimising supply chain management through predictive analytics to enhancing robotic automation for streamlined assembly processes. By harnessing AI technologies in these diverse contexts, manufacturers can unlock efficiencies, improve productivity, and drive innovation across their operations.

## WHAT IS TRUSTWORTHY AI?

Trustworthy AI refers to the development and deployment of AI systems that are secure, robust, transparent, and ethical, and explainable. The term often encompasses a set of principles and techniques aimed at ensuring that AI technology is developed, deployed, and operated in a manner that inspires confidence by the user, developer, and all associated stakeholders.

Trustworthy AI gained prominence with the rapid advancement of AI technology. Traction for trustworthiness began in the 2010s when AI adoption became a topic of importance across industries. Today, AI trust is a crucial topic for safeguarding against any harm that can come from the misuse of this technology and ensuring that an AI model is safe to operate. This lack of trust in AI acts as a bottleneck that is slowing adoption in many industries including manufacturing. Developing trustworthy AI models is an involved process requiring a variety of specialised roles throughout the entirety of the AI development lifecycle, as depicted in Figure 2 and explained in detail in the whitepaper 'Utilising Externally Hosted AI/Generative AI Services in Manufacturing' <sup>[5]</sup>.

In line with the guidance provided by the UK government's Centre for Data Ethics and Innovation (CDEI) and the Department for Science, Innovation and Technology (DSIT) <sup>[6]</sup>. Trustworthy AI revolves around 5 core principles illustrated in Figure 3 and should adhere to important AI assurance techniques throughout the AI development lifecycle. The following sections discuss the respective principles and assurance techniques in more detail, while highlighting the existing standards and frameworks that adequately address them as of November 2023.



# Trustworthy AI in Manufacturing

Trustworthy AI practices and principles are particularly critical for manufacturing applications, where incorrect integration of AI in production systems can be detrimental to productivity and harmful if used in an inappropriate manner. Below are some examples of AI applications in manufacturing and the importance trustworthy AI holds for them.

## AI FOR QUALITY ASSURANCE

In the realm of quality control in manufacturing, AI is harnessed to detect defects, anomalies, and deviations in the production process. Trustworthy AI is of paramount importance in this context, as the reliability and accuracy of the AI system directly influence the quality of the final products. A trustworthy AI solution not only provides precise defect detection but also offers interpretability and explainability, allowing manufacturers to understand why a certain decision was made. This transparency is crucial, especially when product quality is synonymous with safety and regulatory compliance. Moreover, trustworthy AI in quality control ensures consistency and fairness in the inspection process, mitigating the risk of biased decisions that could compromise the reliability of the manufacturing process. This can occur when the AI model produces results that are systematically prejudiced to certain decisions, potentially due to inherent bias in the training dataset. As manufacturers increasingly wish to rely on AI to uphold quality standards, the trustworthy implementation of AI in quality control not only enhances operational efficiency but also fosters confidence in the reliability and fairness of the entire production chain. Companies collaborating across the supply chain can place trust in the consistent quality of AI-evaluated products received from their partners, thereby guaranteeing the quality of their final products.

## PROCESS AND ROBOTIC AUTOMATION

Autonomous robots incorporate AI to automate manu-

facturing functions, traditionally for repetitive and monotonous tasks including picking and placing, welding, painting, assembly, and inspection that free up workers time to focus on more productive tasks. Integrating robots with machine learning allows them to self-learn and become better at tasks at hand or learn new tasks, analysing its own performance to improve over time. Machine vision can enhance capabilities further by enabling better mobility in complex environments while helping with safety when working around human colleagues. Robots in these situations are often referred to as collaborative robots (Cobots for short) as they work in support of their human counterpart and are specifically designed to augment the human worker. Extending this beyond individual tasks, whole processes can be automated, making use of automated robotics, machine learning, and business process automation to streamline the process from start to finish. Using AI enabled automation in production relies heavily on trustworthy AI practices. Ensuring reliability, safety, and transparency in their decision-making processes becomes pivotal, especially when integrating machine learning to enhance their capabilities. Trustworthy AI not only bolsters the efficiency of these systems but also instils confidence in their seamless collaboration with human counterparts, emphasising a safe and productive working environment.

## LARGE LANGUAGE MODELS (LLMS)

In the manufacturing industry, conversational AI and Large Language Models (LLMs) play a pivotal role in simplifying access to unstructured data while offering an intuitive interface for information retrieval. These technologies streamline the interaction with complex datasets, enabling effortless querying of vast amounts of manufacturing-related information. Through chatbots or virtual assistants tailored for manufacturing contexts, conversational AI facilitates quick access to insights and operational details. Simultaneously, LLMs adeptly process textual manufacturing data, providing detailed responses

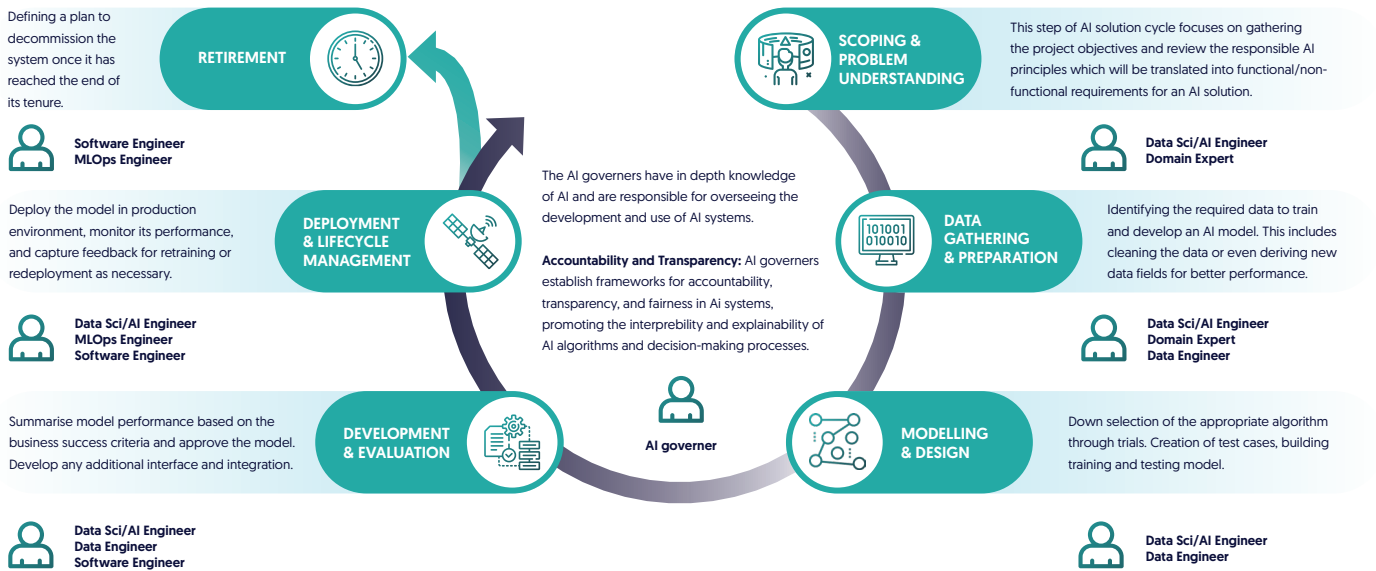


Figure 2: The AI Development Lifecycle<sup>[5]</sup>.

and improving comprehension of unstructured information specific to this sector. Hallucination and invention (the creation of false references where none exist for instance) are problems rooted deep in the heart of how LLMs are structured and trained. The boundary between reliable and unreliable output in an LLM is very complex and hard to discern. These models must be properly assessed against trustworthy AI principles to allow for adoption in critical applications.

## TRUSTWORTHY AI PRINCIPLES

Trustworthy AI principles encompass a set of values that guide the design, development, deployment, and use of AI systems. These principles aim to ensure that AI technologies are developed and applied in a manner that respects governance guidelines, maintains data security, ensures human and asset safety, as well as considering appropriate model transparency.

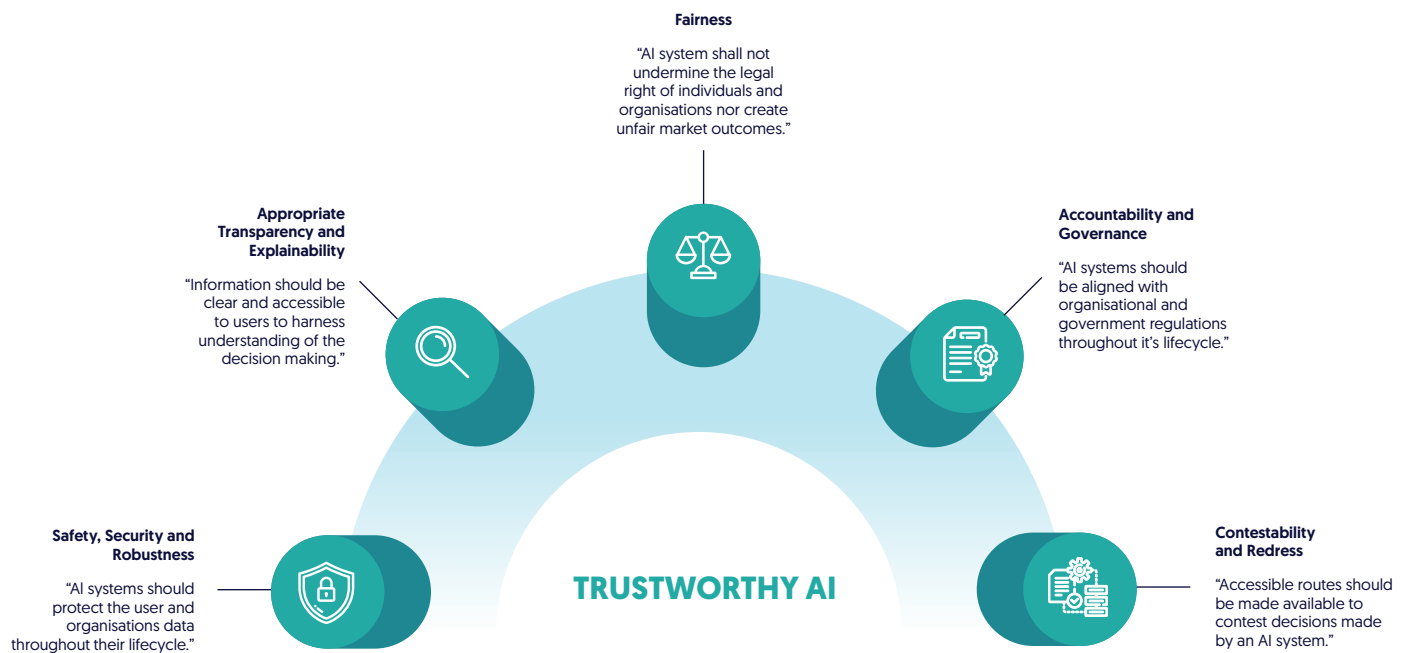


Figure 3: Trustworthy principles.

These principles were introduced by the Organisation for Economic Co-Development (OECD) as part of a recommendation from 2019 meant to underpin future development of AI [7]. The United Kingdom adopted these principles for its approach to AI regulation in 2023 [8] becoming part of a government framework for future development of AI standards and guidance.

Figure 3 shows the five Trustworthy AI principles that the UK adopted as part of its framework for AI regulation. While these principles do not give a clear framework by themselves, they should nevertheless, be used to underpin any development of AI models. Recent frameworks and standards released have looked to develop the understanding of these principles into practical applications.

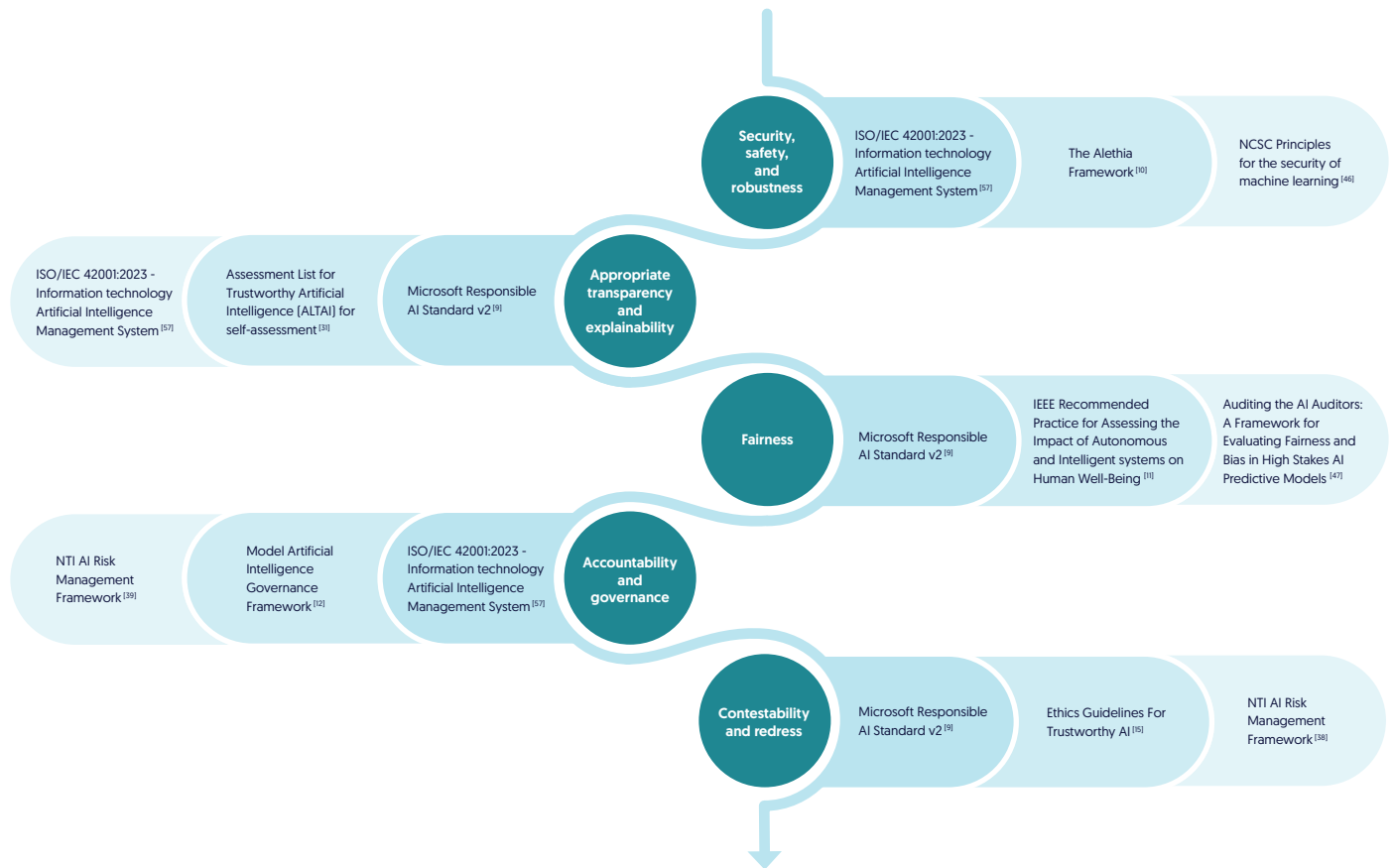


Figure 4. Diagram illustrating the pieces of reviewed literature that most comprehensively cover each trustworthy AI principle across the AI lifecycle


Existing standards and frameworks on trustworthy AI have been reviewed against the trustworthy AI principles and summarised in Figure 4. The figure highlights


the standards that cover each respective pillar most comprehensively out of 40+ reviewed standards, frameworks, policies, and white papers.




# AI Assurance Techniques

Assurance techniques are tools and services that help build confidence or trust in a product, system, or even for an organisation on a wider scale, and are used regularly in industries such as finance. Applying similar assurance techniques on AI systems can help with building trust in AI and will demonstrate the trustworthiness of the AI system and consequently build and maintain trust. Similar to the trustworthy AI principles, Figure 5 highlights the standards that cover each respective assurance technique most comprehensively out of 40+ reviewed standards, frameworks, policies, and white papers. The CDEI has developed a portfolio of assurance techniques in the context of AI-enabled systems, the definitions of these different types of assurance technique can be found below:

 **Impact assessment** – Used to anticipate the effect of a system on environmental, equality, human rights, data protection, or other outcomes. Includes risk assessments and risk management strategies.

 **Compliance audit** – A review of a company's adherence to internal policies and procedures, or external regulations or legal requirements. Specialised types of compliance audit include system and process audits and regulatory inspection.

 **Certification** – A process where an independent body attests that a product, service, organisation, or individual has been tested against, and met, objective standards of quality or performance.



**Bias audit** – Assessing the inputs and outputs of algorithmic systems to determine if there is unfair bias in the input data, the outcome of a decision or classification made by the system.



**Conformity assessment** – Provides assurance that a product, service, or system being supplied meets the expectations specified or claimed, prior to it entering the market. Conformity assessment includes activities such as testing, inspection and certification.



**Impact evaluation** – Similar to impact assessments but are conducted after a system has been implemented in a retrospective manner.



**Formal verification** – Establishes whether a system satisfies some requirements using the formal methods of mathematics. These prove the correctness of an AI system's behaviour and ensure they behave as they should and do not provide incorrect outcomes.



**Performance testing** – Used to assess the performance of a system with respect to predetermined quantitative requirements or benchmarks to ensure it meets the performance requirements of users. Can identify bottlenecks and improvements to AI performance.



Figure 5. Diagram illustrating the pieces of reviewed literature that most comprehensively cover how to complete a particular AI assurance technique across the AI lifecycle.

# Current State of Trustworthy AI

In alignment with national and international initiatives to regulate AI technology <sup>[8]</sup>, multiple standards and frameworks have recently been developed addressing the topic of trustworthy and responsible AI. We have reviewed 40+ publications published before January 2024 including standards, frameworks, policies, and white papers, aligning them with the trustworthy AI principles and AI assurance techniques.

The statistics were collated into heatmap tables literature gaps as presented in Table 1 and Table 2, where darker cells represent intersections better covered in the literature, and lighter cells representing gaps. It is apparent that most existing standards focus the middle stages of the AI development lifecycle with the scoping & problem understanding and the retirement stages remaining poorly explored. This is a significant gap, given that many issues for AI development often stem from poor problem scoping and business problem understanding. The contestability & redress pillar is mostly relevant to the operation & monitoring stage therefore, the gap for the other stages in the AI development lifecycle is expected.

The impact and conformity assessments are well covered in the literature due to their importance. Moreover, they can be easily completed within internal development and governance teams with minimal external involvement, making them popular AI model assurance techniques. Formal certification bodies for AI models are difficult to find due to the complexity of validating standards against industry specific use cases, making it a significant gap in the AI adoption supply chain. Bias audits are important to ensure AI model fairness, a key pillar for trustworthy AI development. However, existing standards do not frequently explore the topic, highlighting the need for additional research and development in this area.

Figure 4 and Figure 5 highlight the literature that respec-

tively cover the trustworthy AI pillars and AI assurance techniques most comprehensively out of 40+ reviewed standards, frameworks, policies, and white papers. The Microsoft Responsible AI Standard, v2 <sup>[50]</sup>, introduced in 2022, offers a comprehensive blueprint describing five crucial pillars: Accountability, Transparency, Fairness, Reliability & Safety, and Privacy & Security. Each pillar details specific goals throughout the AI development lifecycle, aiming for responsible and ethical deployment. However, while this standard provides a robust foundation, it remains very high level and requires further guidelines for its practical implementation and adaptability to diverse AI applications in manufacturing.

In tandem with Microsoft's framework, the NIST AI Risk Management Framework <sup>[39]</sup>, also unveiled in 2022 provides a comprehensive framework that seeks to assist organisations in understanding AI system contexts and their impact on individuals and communities, urging critical assessment of potential risks and impacts. Nevertheless, challenges in implementing this framework across diverse AI contexts persist, requiring tailored approaches and seamless integration into manufacturing domains.

Moreover, the Assessment List for Trustworthy Artificial Intelligence [ALTAI] <sup>[5]</sup> from the European Commission, initiated in 2019, provides a self-assessment tool for AI developers grounded in fundamental ethical principles. This framework aims to foster trustworthiness by enabling self-evaluation against key ethical principles aligned with EU law. Similarly, like the AI Risk Management Framework <sup>[39]</sup>, ALTAI accentuates the evaluation of risks and impacts of AI systems within organisations, emphasising mitigation strategies. Yet, challenges in practical implementation and adaptability across diverse AI contexts, such as manufacturing persist. This necessitates tailored strategies for different applications and wider adoption initiatives to enhance its effectiveness.



The ISO/IEC 42001:2023 - Information technology. Artificial intelligence. Management system<sup>[57]</sup> is an international standard that outlines the requirements for developing and maintaining AI systems within an organisation. It covers most of the Trustworthy AI pillars, overlaps with the NIST Risk management Framework<sup>[39]</sup>, and discusses how AI models should integrate with other systems, which is a critical yet poorly explored topic. Although it provides guidance on how AI models should be developed to ensure safe, robust, and secure systems, there are gaps, particularly with technical and ethical themes. Additionally, as with most other documents, it lacks specifics for application to industries such as manufacturing.

Some of the existing standards in the literature effectively cover specific contexts domains such as medicine, finance, and commerce. However, the manufacturing industry requires special considerations given the variability of use cases, data streams and considerations required for the development of effective systems. Moreover, the frameworks and standards remain a paper-based exercise that explain ‘what’ should be covered; there is a limitation of practical examples on ‘how’ that can be achieved.



“Most frameworks outline ‘what’ trustworthy AI is yet lack practical explanation of ‘how’ to achieve it.”<sup>[10]</sup>



	Impact assessment	Compliance audit	Certification	Bias audit	Conformity assessment	Impact evaluation	Formal verification	Performance testing	Other ongoing testing
Scoping & problem understanding									
Data gathering & preparation									
Modelling & design									
Development & evaluation									
Deployment									
Live orientation & monitoring									
Retirement									

Table 1. Heatmap displaying the of coverage AI assurance techniques across the AI lifecycle in the literature of AI standards and frameworks.

	Safety, security and robustness	Appropriate transparency and explainability	Fairness	Accountability and governance	Contestibility and redress
Scoping & problem understanding					
Data gathering & preparation					
Modelling & design					
Development & evaluation					
Deployment					
Live orientation & monitoring					
Retirement					

Legend	
High coverage	
Medium coverage	
Low coverage	
Minimal or no coverage	
N/A	

Table 2. Heatmap displaying the of coverage trustworthy AI pillars across the AI lifecycle in the literature of AI standards and frameworks.

# Framework for Implementing Trustworthy AI

As can be seen from this paper, there continues to be a gap in the guidance for the practical implementation of trustworthy AI principles and assurance techniques. While the knowledge of these principles and techniques exists through a number of research papers, standards, and frameworks there are limited approaches to establishing Trustworthy AI in the manufacturing sector specifically. The approaches that are available also do not commonly inform when the different assurance techniques should be completed throughout the AI development lifecycle. In short, the frameworks outline what trustworthy AI is yet lack practical explanation of when it is necessary and how to achieve it.

Following on from the research that was gathered for this paper, the Manufacturing Technology Centre (MTC) sought to create a framework which could generate

practical applications of Trustworthy AI principles and assurance techniques for the manufacturing sector.

This framework expands on currently existing standards by providing guidance in identified gaps in current literature such as assurance assessments. It also provides users with a clear checklist at establishing trustworthy AI in their systems looking at holistically at trust in the AI development lifecycle.

The MTC's trustworthy AI framework has been developed to address the gaps in the literature. An example of the of the framework can be seen in Figure 6 and the full version is available on request. For any questions or feedback, please get in touch with the MTC's AI governance team on: [aigovernance@the-mtc.org](mailto:aigovernance@the-mtc.org).

# Conclusion

This paper demonstrates the current standards and guidance for establishing Trustworthy AI. While there is a lot of literature that is available that can be used, these are often not tailored to the manufacturing sector, nor do they provide a single clear and easy approach for AI developers to create trustworthy AI for their systems.

In this paper, the gaps to creating trustworthy AI have been identified and shows that these gaps are a restricting factor in establishing trustworthy AI and deploying trustworthy AI solutions in the future.

While this area of research continues to grow as more standards and guidance is released, there is a demand

for a unified framework to developing trust in AI systems now as the technology surrounding AI also continues to develop. The developed framework featured in this paper demonstrates one of the possible solutions to this problem in the form of a checklist framework which will enable users to understand what trustworthy AI is and when to apply principles and techniques and finally, how to demonstrate those principles and techniques for AI developers.

For the detailed Trustworthy AI framework please get in touch with the MTC's AI governance team at: [aigovernance@the-mtc.org](mailto:aigovernance@the-mtc.org).

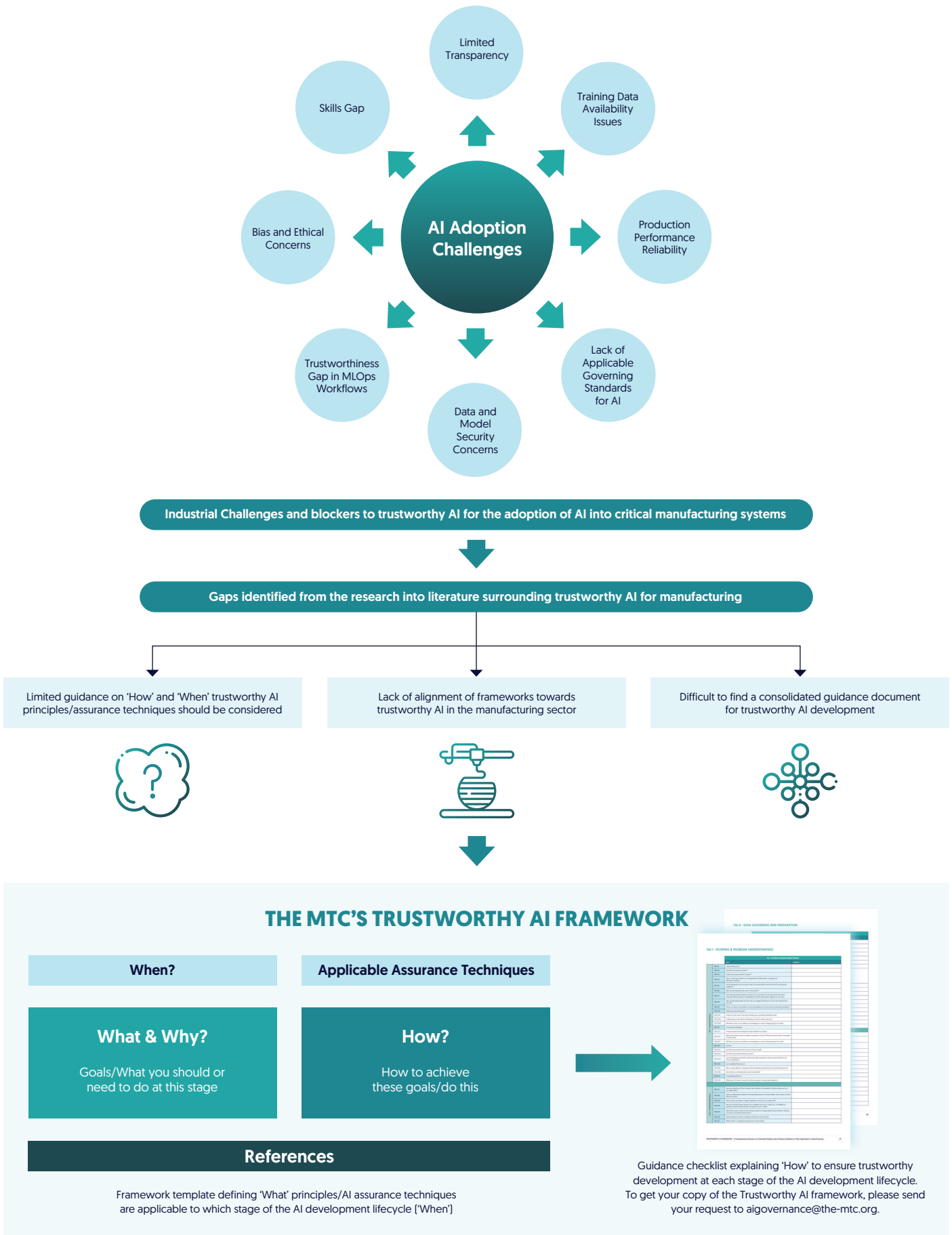


Figure 6. An outline of the gaps in the AI standard literature and example of the developed trustworthy AI framework.



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