From Smart Manufacturing to Agentic Manufacturing

A U.S. Perspective on AI-Enabled Industrial Transformation

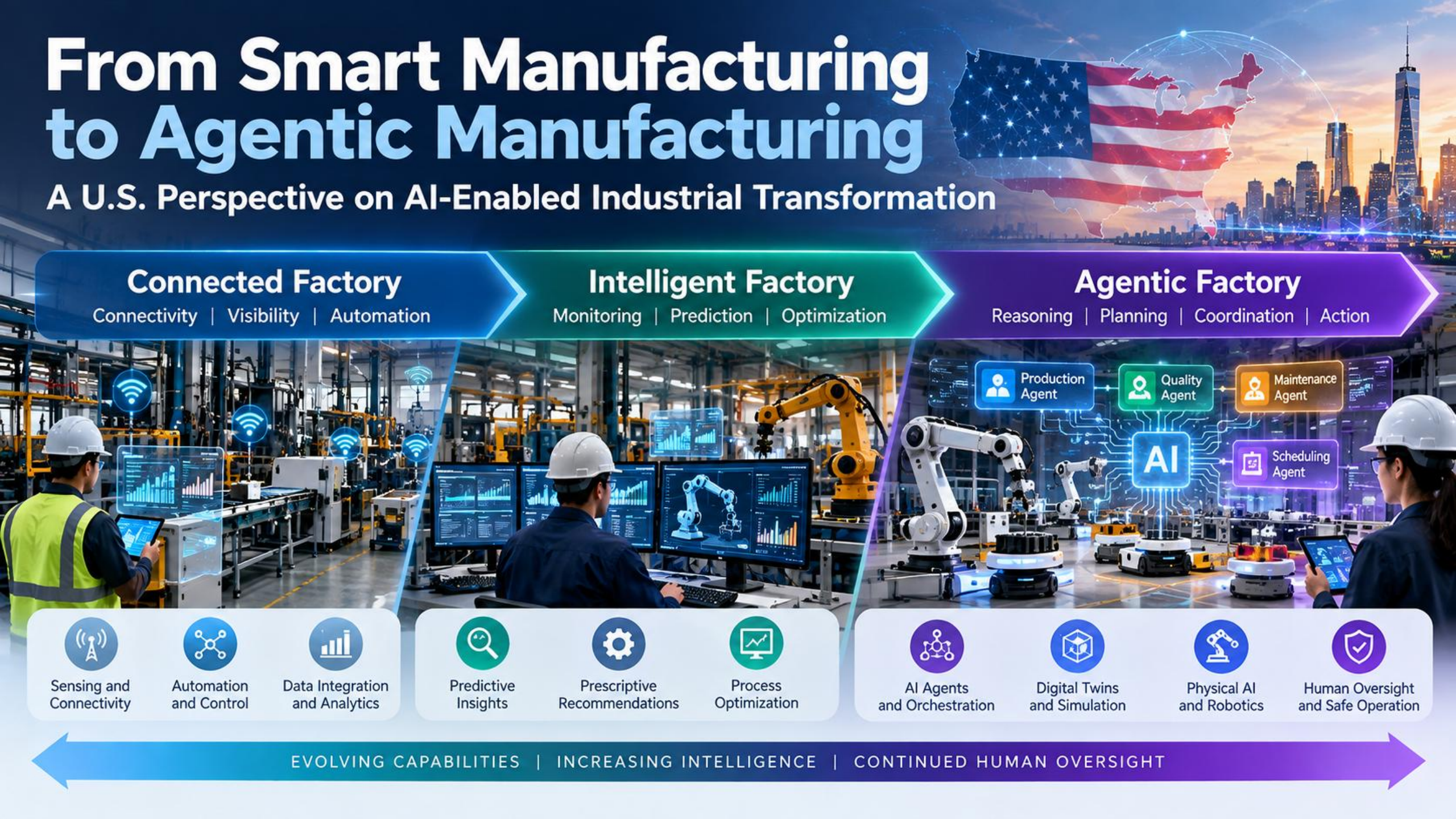
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From Smart Manufacturing to Agentic Manufacturing

A U.S. Perspective on AI-Enabled Industrial Transformation



Why the United States Is Prioritizing AI-Enabled Manufacturing

Economic, industrial, and national priorities.



Productivity & Competitiveness

Higher yield, quality, less downtime, lower cost, faster development.

- Operational efficiency
- Quality and reliability
- Reduced downtime
- Faster time to market



Resilience & National Security

Strong domestic manufacturing, industrial base, and adaptive supply chains.

- Domestic production capacity
- Diversified and resilient supply chains
- Critical industries and materials
- Secure and trusted industrial infrastructure



Industrial AI



Technology Leadership

Advance AI engineering, robotics, materials discovery, and digital infrastructure.

- Next-generation AI and robotics
- Digital twins and simulation
- Advanced materials and processes
- U.S. innovation ecosystem



Workforce Transformation

Augment operators and engineers and prepare workers for changing tasks.

- Human–AI collaboration
- Upskilling and reskilling
- Safer and more engaging work
- Expanded opportunity and talent pipeline



Policy Context

Federal strategies are aligned with AI-enabled manufacturing to strengthen the economy, industrial base, and national security.

America's AI Action Plan (July 2025)

- Accelerate AI innovation
- Build AI infrastructure
- Advance AI diplomacy & security

Supports manufacturing, scientific AI, data, and workforce capabilities.

Manufacturing USA Strategic Plan (Dec. 2025)

- Competitiveness
- Technology transition
- Workforce development
- Institute network

Policy priorities do not imply that every initiative is fully funded, commercially mature, or universally adopted.

Industrial AI is strategically important to U.S. competitiveness, resilience, innovation, and workforce capacity.

U.S. Industrial AI Research and Innovation Ecosystem

Who creates and advances industrial AI technologies?

INNOVATION
PEOPLE
PARTNERSHIPS
A STRONGER
MANUFACTURING TOMORROW

1 National Priorities & Federal Support

STRATEGIC DIRECTION | FUNDING | MISSION NEEDS



NIST
Measurement science, trustworthy AI, standards.



DOE
National laboratories, scientific AI, digital twins.



DoD
Industrial-base resilience, technology transition.



NSF
Foundational AI, robotics, workforce research.

2 Research & Enabling Infrastructure

KNOWLEDGE | FACILITIES | STANDARDS | COMPUTE & DATA



Universities
Fundamental research and talent development.



National Laboratories
Large-scale R&D and test facilities.



Standards & Reference Methods
Interoperability, benchmarks, validation.



Advanced Computing & Data Infrastructure
AI models, secure data, computing resources.

3 Collaboration & Industrial Innovation

PARTNERSHIPS | TECHNOLOGY TRANSFER | REAL-WORLD IMPACT



Industry, technology developers, and public–private partnerships
Manufacturing USA and related collaborations



Examples of Initiatives

NIST – AI for Manufacturing
human–AI teaming, fit-for-purpose, interoperability.

NIST – AIMS
metrology, manufacturing physics, AI for reliable prediction.

DOE – Genesis Mission
generative and agentic AI, industrial digital twins, human-in-the-loop decisions.



International comparison: comparable in intent, but structurally different from Japanese industry–research networks and the German Fraunhofer model.

Key takeaway: The U.S. model joins foundational research with measurement science, partnerships, and industrial collaboration to advance AI–enabled manufacturing.

From Research to Industrial Deployment

The Manufacturing USA model

Manufacturing USA institutes convene **public–private consortia** for precompetitive R&D, demonstration, adoption, and workforce development.

1 Research

Universities
Discovery, talent, and new ideas

National laboratories
World-class facilities and expertise

Foundational R&D
New materials, processes, AI, and manufacturing technologies



2 Manufacturing USA

Public–private consortia

Bringing together industry, academia, and government to advance precompetitive R&D and drive adoption.

- CESMII — Smart manufacturing and industrial data
- MxD — Digital manufacturing and cybersecurity
- America Makes — Additive manufacturing and advanced materials



3 Validation & Demonstration

Testbeds
Real-world manufacturing environments

Pilot projects
De-risk and prove value at scale

Interoperability
Connect systems, data, and supply chains

Standards-based evaluation
Objective assessment of performance and safety

De-risking of technology
Reduce technical, operational, and commercial risk



4 Workforce & Technology Transfer

Workforce development
Build the skills for advanced manufacturing and AI

Training
Hands-on learning and certifications

Adoption support
Technical assistance for small and medium-sized manufacturers

Pathways to industry
Internships, industry collaborations, and technology transfer



5 Scalable Industrial Deployment

Higher productivity and quality
More capable, consistent, and efficient production

Lower cost and downtime
Optimized operations and greater reliability

Faster innovation
Shorter time from idea to market

More resilient supply chains
Greater flexibility and domestic capability

Sustainable manufacturing
Lower emissions, less waste, and more efficient use of resources



Key takeaway: Manufacturing USA helps translate research innovations into validated and scalable manufacturing capabilities.

A priority area for U.S. policy; not every initiative is equally mature or fully deployed.



From Generative AI to Agentic and Physical AI: The Emerging Manufacturing Paradigm

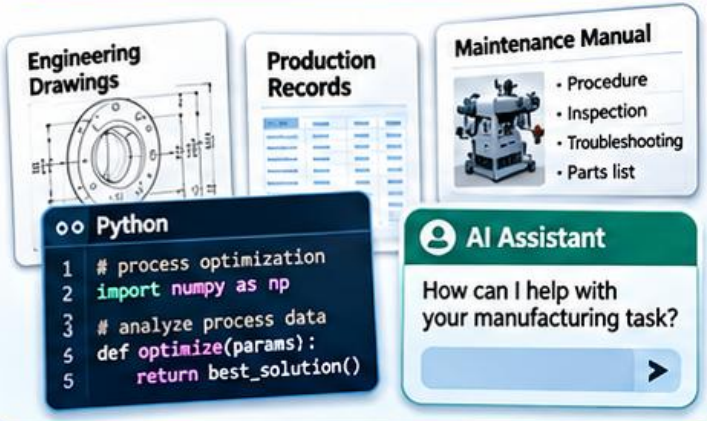
Core technology transformation



Generative AI as an industrial knowledge interface

- Interpret engineering documentation, production records, and maintenance procedures
- Provide context-specific asistance to operators and engineers
- Generate candidate plans, instructions, code, analyses, and design alternatives

Generated results still require validation



Manufacturing objectives & constraints

Quality | Cost | Throughput | Energy | Safety

Agent orchestration



Tool innovation and data exchange ↕ Analysis results, insights and options

Industrial tools

Digital twins | Physics models | Simulations | Optimization | APIs

Validated decision → **Human approval / bounded authorization** → **Physical action**

Decision authority and control authority are governed separately

Agentic AI as a coordinator of manufacturing decisions

- Interpret goals such as reducing scrap, increasing throughput, or lowering energy intensity
- Decompose tasks and retrieve relevant industrial knowledge
- Invoke simulation, optimization, analytical models, or enterprise software
- Coordinate specialized agents and recommend or perform only explicitly authorized actions

AI Agent Planner

1. Understand objective ✓
2. Decompose tasks ✓
3. Retrieve knowledge ✓
4. Use tools (simulation, ERP, etc.)
5. Generate options ···
6. Recommend / execute ···



Physical AI and industrial opportunities

- Link perception, planning, and reasoning with robotics, machinery, and the physical environment
- Support adaptive inspection, maintenance, scheduling, process optimization, robotics, and energy management
- Require verified operating boundaries, deterministic protection mechanisms, and suitable response times



Technical distinction | The ability to reason or invoke a digital tool does not grant authority to control machinery. Physical execution requires independent safety, authorization, and verification.

Key takeaway | Agentic manufacturing combines specialized AI reasoning, industrial tools, and coordination, with separately governed decision and control authority.

Manufacturing Data Foundations:
Prerequisite for Scalable Industrial AI

INTEROPERABLE DATA
CONTEXTUALIZED KNOWLEDGE
TRUSTWORTHY AI

INDUSTRIAL DATA SOURCES

- Machines & Sensors

- PLCs & Historians

- MES & ERP

- Inspection & Quality


Legacy systems, inconsistent meaning and missing context limit AI reliability.

DATA INTEGRATION AND CONTEXTUALIZATION

CONNECT
Interoperable data exchange

- OPC UA
- MQTT
- Industrial APIs

UNDERSTAND
Common meaning and industrial context

- Semantic models and standards
- Engineering units and timestamps
- Equipment states and process context

TRACE
End-to-end traceability and digital thread

- Digital thread across lifecycle
- Product identity and cyber-physical passports
- Provenance and data lineage
- Digital twins (assets and products)

AI-READY INDUSTRIAL KNOWLEDGE
Interoperable
Contextualized
Traceable
Trustworthy

INDUSTRIAL AI AND AGENTIC DECISION-MAKING

- Process optimization
- Predictive maintenance
- Quality and inspection
- Scheduling and planning
- Energy management
- Root-cause analysis

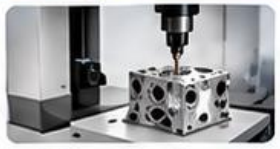
Time-aligned | Interoperable | Traceable | Secure | Fit for purpose

EXAMPLE: PRODUCT DIGITAL THREAD

Design → Production → Inspection → Digital Product Passport → Lifecycle


CAD, materials and specifications


Process conditions, equipment data


Dimensional and NDT results


- Product identity
- Material and process history
- Inspection records
- Operating conditions
- Maintenance history


Service data, performance and end-of-life

More data are not enough: industrial AI needs interoperable, contextualized, traceable, trustworthy data.

NIST Digital Thread for Smart Manufacturing | ASTM/CESMII AI in Manufacturing Systems Workshop, Oct, 2026

Digital Twins and Multi-Agent Systems:
The Architecture of Agentic Manufacturing

Integrated reference architecture



INTELLIGENT MANUFACTURING
RESILIENT OPERATIONS
SUSTAINABLE INDUSTRY

5 Intelligent orchestration

Planning | Agents | Tool invocation

Scheduling Agent ↔ Quality Agent ↔ **Agent Orchestration & Task Planning** ↔ Maintenance Agent ↔ Optimization Agent

4 Models and knowledge

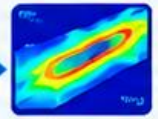
Digital twins | Physics | Simulation



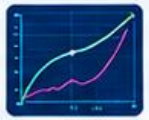
Physical asset



Digital twin ↔ **Digital Twin** ↔



Physics models



Simulation

3 Context

Digital thread | Semantics | Traceability

Product digital thread ↔ BOM & genealogy ↔ **Shared Industrial Knowledge** ↔ Process context ↔ Quality records ↔ Lifecycle traceability

2 Connectivity

Sensors | IIoT | OPC UA | Integration

Sensors & edge devices ↔ IIoT networks (5G/TSN) ↔ OPC UA & industrial protocols ↔ Cloud & enterprise integration ↔ Data flow & event streaming

1 Physical systems

Machines | Processes | Inspection



CNC machines | Robotic cells | Assembly & processing | In-line inspection (vision/AI) | Material handling

Cross-cutting governance and assurance

- Human oversight
- Cybersecurity
- Validation
- Safety
- Auditability

Illustrative closed-loop workflow (conceptual)

1. Quality Agent detects an emerging defect trend.
2. Root-Cause Agent examines operating records and process history.
3. Digital Twin evaluates possible explanations and simulated corrections.
4. Optimization Agent proposes revised production parameters.
5. Validation layer checks uncertainty, process limits, and safety constraints.
6. Human approves the action, or a verified low-risk action executes within predefined limits.
7. Production and inspection results feed back into models and future decisions.

Continuous improvement

Evidence versus vision

A propesed reference model — not a claim that fully autonomous multi-agent factories are already in routine operation.

Key takeaway: Agentic manufacturing must be grounded in industrial knowledge, validated models, and operating constraints — not only general-purpose language models.

Human–AI Teaming: The Appropriate Level of Industrial Autonomy

Human-centered intelligence and bounded autonomy

PEOPLE
INSIGHT
AI
SAFER OPERATIONS
STRONGER OUTCOMES

Complementary strengths



Humans

Tacit knowledge
Context and nuance from real-world experience

Domain experience
Deep operational and process knowledge

Creativity
Novel solutions and out-of-the-box thinking

Situational judgment
Holistic assessment in complex situations

Accountability
Ethical, legal, and organizational responsibility

Human–AI teaming improves timeliness, quality, and consistency of engineering decisions.

AI

Continuous monitoring
24/7 analysis of operational data and conditions

Pattern recognition
Identify complex patterns and early signals

Predictive capability
Forecast conditions and risks

Knowledge retrieval
Instant access to vast documentation and best practices

Computational scale
Analyze, multiple scenarios at speed and scale

Appropriate level of industrial autonomy

Conceptual framework — not an official NIST classification.

Human oversight across all levels

Humans remain in the loop, with increasing validation and safeguards as autonomy increases.

Level 1 Assistive



AI responsibility
Monitoring and information retrieval

Human responsibility
Interpret and decide.

Level 2 Predictive



AI responsibility
Forecast conditions and risks

Human responsibility
Assess and respond.

Level 3 Advisory



AI responsibility
Recommend alternatives

Human responsibility
Review and approve.

Level 4 Bounded autonomy



AI responsibility
Execute validated actions within defined limits

Human responsibility
Supervise and intervene.

Level 5 Supervised autonomy



AI responsibility
Coordinate authorized operations

Human responsibility
Maintain oversight and accountability.

Low — More AI authority — High

Low — Stronger validation and safeguards — High

> "The objective should not be maximum autonomy. It should be the **appropriate level of autonomy** for the risk, uncertainty, and consequences of each manufacturing decision.

Risk-governed design principle

Risk
Likelihood and nature of harm

+

Uncertainty
Quality and completeness of information

+

Validation maturity
Proven reliability, testing and operational experience

+

Consequences of failure
Safety, environmental, financial, and reputational impacts

→

Determine appropriate autonomy.

Key takeaway: **Human–AI collaboration is a central design choice,** not necessarily a temporary stage before full autonomy.

Trust, Confidence, and Industrial Assurance
From Research to Reliable Deployment

Demonstrating Safety, Reliability and Value for Real-World Manufacturing



What can go wrong?

DATA
- Incomplete or biased datasets
- Missing context and semantics
- Legacy integration challenges

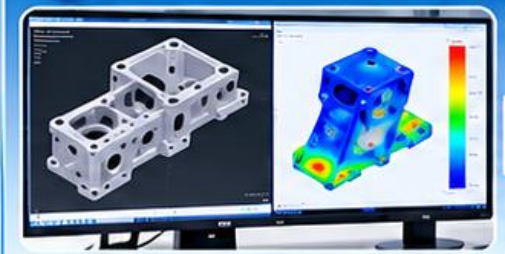
MODELS
- Uncertainty and hallucinations
- Brittleness and performance drift
- Insufficient explainability

OPERATIONS
- Unreliable or unsafe actions
- Cybersecurity and IP protection
- Unclear accountability
- Deployment cost and workforce skills
- Scalability, especially for smaller manufacturers

Phased Approach to Reliable Deployment

Increasing trust, validation and operational value

1 Offline Validation
Test models and tools



- Use representative datasets
- Compare with physics models
- Evaluate accuracy and uncertainty

2 Shadow Evaluation
Observe only (no control)



- Run in parallel with operations
- Compare AI recommendations with actual outcomes
- Identify gaps and risks

3 Human-Approved Decisions
Verify and authorize



- Review AI recommendations
- Leverage human expertise and judgment
- Build trust and refine models

4 Bounded Execution
Validated actions within limits



- Authorize constrained actions
- Enforce safety and process limits
- Monitor performance in real time

5 Continuous Assurance
Monitor, learn and improve



- Track performance and drift
- Analyze incidents and recovery
- Continuous model validation and improvement

Measurement Science, Standards and Guidance

NIST AIMS
- Traceable measurement
- Physics-based verification for improved predictions

NIST AI for Manufacturing
- Human–AI collaboration
- Integration metrics
- Performance evaluation

ASTM/CESMII Workshop (October 2026)
- Common terminology and semantics
- Data quality and interoperability
- Evaluation, safety and cybersecurity
- Human–AI teaming standards

AI Risk Management Framework (AI RMF)
- Voluntary risk-assessment guidance
- Supports trustworthy and responsible deployment (not a manufacturing-specific mandatory standard)

Trust must be engineered, measured, validated, and continuously maintained— not inferred from the sophistication of the AI system.

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Selected primary sources. Click source links for full materials. Conceptual diagrams synthesize these sources; they are not official standards or architectures.


Thank You!
AI
Questions?