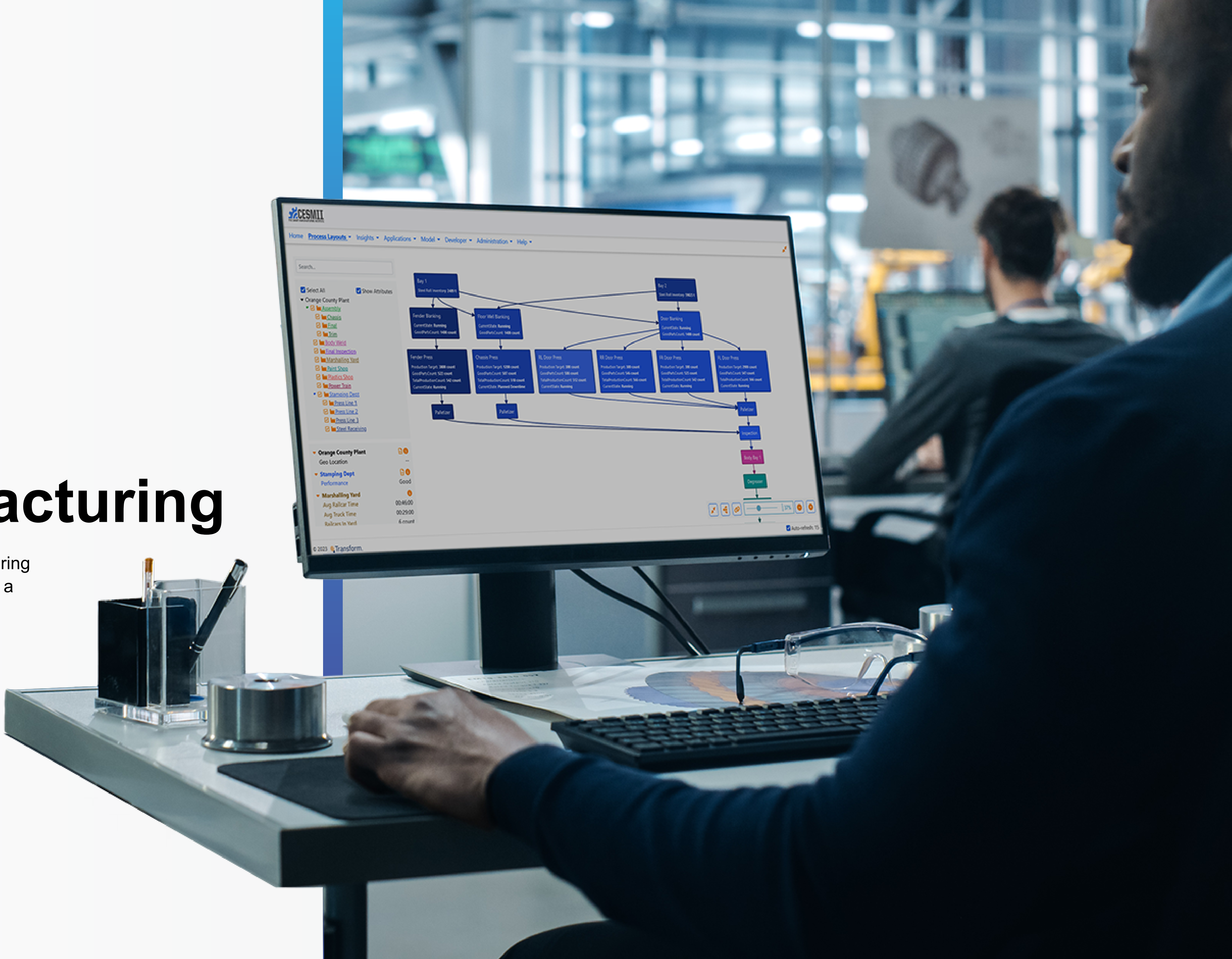
USCAR
UNITED STATES COUNCIL FOR AUTOMOTIVE RESEARCH

Roadmap for Automotive Smart Manufacturing

This Roadmap for Automotive Smart Manufacturing focuses on three vital strategies that will enable a more productive, competitive, and resilient automotive manufacturing environment here in the United States.



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CESMII
THE SMART MANUFACTURING INSTITUTE

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EXECUTIVE SUMMARY

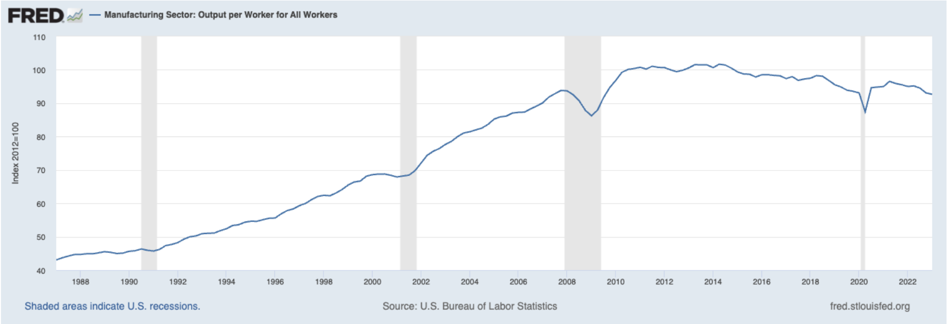
Document Purpose

The Automotive manufacturing landscape continues to face enormous headwinds, putting stress on every aspect of the business, including the global supply network. Adding to that is the market move toward electrification, new sustainability requirements, and significant worker retention issues. OEMs are being forced to re-examine every aspect of their business, paving the way for a more resilient and collaborative approach to address these challenges.

The post-pandemic move toward supply chain regionalization is also adding stress to an already heavily burdened manufacturing workforce. This is further exacerbated by the unprecedented reality that manufacturing productivity by worker is at historic lows – and still declining – here in the US. While the reasons for this decline are multi-faceted, there is a growing sense of urgency that we need to improve US manufacturing productivity, competitiveness, and resilience.

All of this points to a critical need to rethink the way we use data to empower people and inform strategies, both for real time operations, and on a longer horizon for resource planning and predictions.

FIGURE 1



Source: https://fred.stlouisfed.org/

FIGURE 2

Value Creation	Great Strategies	Productive Operations	Future-Proof Architectures
Shareholders Corporate Plants Functions	Resilient Supply Chains Agile Innovation Engaged Workforce Sustainable Operations	Empowered, Innovative Workforce Connected Operations Connected Suppliers	Interoperability Engaged Ecosystem Standards-based where necessary Crowd-sourced where possibly
Requires →	Requires →	Requires →	

This Automotive Smart Manufacturing Roadmap focuses on three vital strategies that will enable a more productive, competitive, and resilient automotive manufacturing environment here in the United States. We will address the need for a connected workforce, resilient and modern manufacturing IT infrastructure, and a Smart Manufacturing Mindset that will foster innovation and collaboration with all key stakeholder groups, including suppliers, technology partners, machine builders, system integrators, etc.

1. **Collaborative** strategies enabling plants connected to the enterprise and supply chains for real-time data-driven business orchestration.

   Goal: flexible and agile processes and supply chains easily reconfigured for changing market demands

2. **Enable** innovation through application and data interoperability based on standardized, open interfaces that eliminate data silos, stovepipe architectures and vendor lock-in.

   Goal: reduce complexity, and improve efficiency and innovation agility

3. **Develop** a Smart Manufacturing Mindset™, aligning education, workforce development and continuous improvement strategies to create data driven cultures.

   Goal: organizational structures that align resources and people for SM success

METHODS USED

Survey

CESMII performed a survey of leaders within each USCAR member company to understand priorities and current thinking on Smart Manufacturing. Eight topics were presented for input: system interoperability and data flow, federation of data structures and breaking down of digital silos, smart application development, prescriptive root cause analysis, supply chain data exchange, workflow orchestration, dynamic asset configuration, and connected worker efforts. Tertiary priorities included cybersecurity, access to non-structured or semi-structured data, and wireless networking considerations.

The highest priority, highest consensus strategies identified by USCAR members were interoperability of systems, data structure federation, and accelerating the development of smart applications. Prescriptive root cause was a close runner-up, but with a higher standard deviation than the top three, which were virtually uniform in consensus.

1. **System interoperability and data flow**
2. **Federation of data structures and breaking down of digital silos**
3. **Smart application development**
4. **Prescriptive root cause analysis**
5. **Supply chain data exchange**
6. **Workflow Orchestration**
7. **Dynamic asset configuration**
8. **Connected worker efforts**

Interviews

CESMII conducted a series of interviews, both with the collective USCAR teams as well as with the individual stakeholder organizations. These interviews provided us with a broad view of the current state of the automotive industry, as well as the business, cultural and technology challenges that are shaping their strategies. We have distilled these Automotive Smart Manufacturing challenges into the following areas:

- Manufacturing productivity initiatives that are not constrained by lack of information access and the complexity of legacy manufacturing systems
- Smooth, successful new program launches with respect to time, cost, and quality – with accurate quality and production data during all stages of the program launch curve
- Addressing workforce churn with a more intuitive, engaging and accommodating experience
- More granular and real-time data from Tier 1 suppliers (birth history, quality, carbon footprint, etc.)
- Revitalized and digitized quality, safety and continuous improvement programs that enable more rapid innovation
- Corporate strategies and funding aligned with Smart Manufacturing value creation expectations

Analysis of Emerging International Standards

CESMII participates in ongoing discussions with similarly focused consortiums and working groups in Europe, Labs Industrie 4.0 (LNI) OPC Foundation, Mechanical Engineering Industry Association (VDMA), and Japan (Japan's Robot Revolution) seeking to define and harmonize on standards, common approaches, and best practices for international information exchange. In the European Union, interoperability of data is a key tool in the creation of, and adherence to, regulation related to efficiency and emissions, and is considered strategic in improving supply chain responsiveness and product quality. While US requirements are different, CESMII's strategy to identify, invest in and advocate for standards-based interoperability can help enable USCAR to engage in a global supply chain, and has contributed to the roadmap presented here.

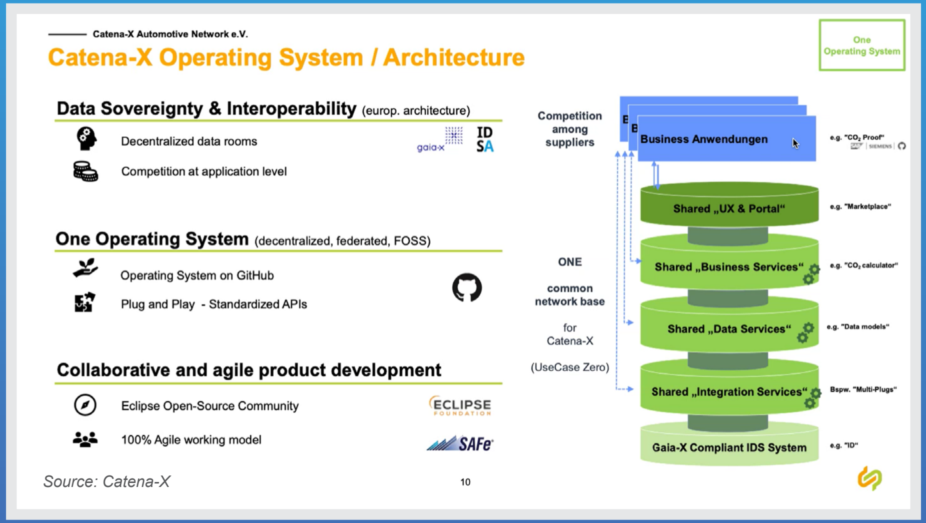
Other Inputs

While international efforts, and CESMII research within USCAR informs this roadmap, CESMII also has the benefit of input from a wide variety of manufacturers in the supply chain, as well as peer feedback on international regulation and industry standardization, and exposure to innovative research on common manufacturing problems.

In developing this roadmap, CESMII also drew on deep industry expertise from its membership, and consultants hired to focus on developing the roadmap. Finally, CESMII principals include leaders and developers of software that both historically and presently support the automotive manufacturing sector.

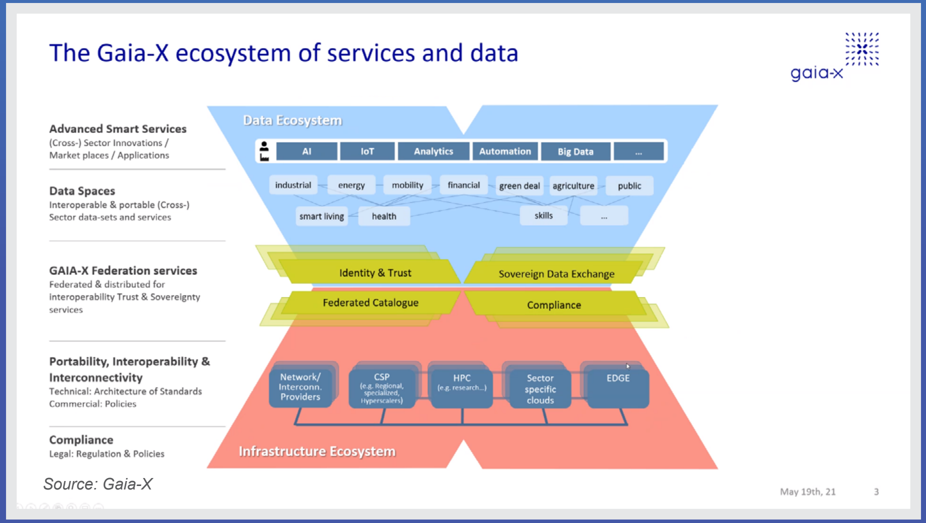
EU Efforts at Integrated Manufacturing Platforms based on Information Interoperability

FIGURE 3



Source: Catena-X

FIGURE 4



Source: Gaia-X

LANDSCAPE

Many of the challenges facing the automotive sector are a result of the way manufacturing technology has evolved. At CESMII, we categorize the technology challenges at three distinct levels: incoherent data sources, incomplete and fractious Information Modeling, and application and analysis architecture not designed for interoperability. Of those three categories, the Information Modeling problem is the most impactful, and generally least understood – even by practitioners.

An Information Model describes the data available from a given source, in the context of a system. An application of that model could be a component in a machine, it could also be a participant in a supply chain: Information Models scale. A good Information Model includes a complete picture of all the systems and their components across a domain to be analyzed. In other words, to perform useful analysis across a supply chain Information Model, the analytic must be able to "dive deep" into the producers and consumers in the chain, the systems those participants employ, and the components that make up those systems. The term Information Model is a broad one and has other names: in generative Large Language Model (LLM) AI, the Information Model contains "tokens" and relationships between tokens; in more traditional machine-learning approaches, the Information Model contains "features"; in mathematical analysis, the Information Model includes variables – both dependent and independent. In all cases, the output of the analysis ideally contributes back to the Information Model, enriching it and expanding the data available for other constituents to analyze.

In manufacturing technology, this is not the case. Information Models are rarely constructed as such, but are inferred or hand-built after the fact, and account for only part of the information an enterprise needs. Each tool's model is held privately, as part of a particular vendor's ecosystem, with limited allowance for sharing its data and almost none for sharing its Information Model. Occasionally this is a deliberate decision by the vendor, but often the cause is more innocuous than that: when we were building this technology, we just didn't know any better.

Modern revelations about the power of an Information Model, and recent offerings in generative AI have begun to demonstrate how little we've truly tapped the power of the Internet, and how its systems were designed. The Internet presents a loose graph of related data. Hyperlinks between content reveal relationships in an explicit, measurable fashion. More private networks, such as Facebook, harden those relationships, defining a tangible, traceable graph between people, interests, viewpoints, and content. Used maliciously, this graph can be exploited to mislead or incite; used appropriately, the graph can be used to inform, educate, and connect. As a tool, it is morally ambiguous – as a technology, it is incredibly powerful. ChatGPT can use content relationships in the Internet Information Model, and context tokens in a conversation Information Model, to produce content that may not always be accurate, but is increasingly convincing. LLMs exploit explicit relationships in Information Models to produce insight and create value. In manufacturing, we lack a cohesive strategy, or even common technology, for capturing such relationships...

> **At the heart of the problem is a duality in the technologies that we leverage. When we discuss the IT/OT divide, it is not just a difference in practitioner priorities or contexts, it is that each side of the divide is the product of a parallel evolution.**

The Information Model in OT technology largely evolved from electrical diagrams; it includes logical flow and some notion of semantics but is usually derived from the control problem. Inconsistent tag naming conventions, differences in protocol implementation, and technology vendors at Levels 0-2 of the Purdue Model attempting to differentiate themselves with unique and incompatible implementations are only symptoms of the underlying reality that control theory is not the same as information theory.

IT technology, on the other hand, has evolved from Object-Oriented Programming (OOP) principles. In recent times, IT practitioners have been rethinking some of those approaches, but for most of the past three decades, a basic adherence to the notion of object orientation has been the common denominator in software development. Rather than thinking about electrical signals and flow, IT software models everything – explicitly, in strongly-typed languages that require an up-front Class definition, or implicitly in loosely typed languages. Furthermore, OOP expects objects to be in relationship with each other. Even the most basic scripting languages support inheritance of some kind.

When we cross the divide, somewhere around Level 3 of the Purdue Model, we are faced not only with the need to marshal and aggregate multiple data sources that speak different languages and use different constructs, but we also must model the incoming data in a way that information software can make sense of it. Numerous attempts have been made by vendors like OSI, PTC ThingWorx, Rockwell Automation and GE. Invariably these offerings include an ecosystem “trap” that tries to lock manufacturers into that vendor’s offerings.

Equally invariably, those vendors are incapable of solving every manufacturing problem within their offerings. Some have been more successful than others at creating a third-party ecosystem that augments the vendor’s own, but a proprietary and incomplete lock on the Information Model remains a reality that has constrained manufacturing technology evolution. While the theory of constructing an “after-the-fact” Information Model to make sense of disparate manufacturing data was a good one, the implementations lacked the openness, consistency, and interoperability of more-easily exploitable networks that tools like ChatGPT are currently benefiting from.

In this roadmap, CESMII has leveraged its 5+ years of engaging with manufacturers, and a team with more than 150 years of combined manufacturing experience, investing in innovation, and re-thinking – alongside some of the aforementioned vendors – to forge a better approach to constructing an open, organic, and interoperable Information Model for manufacturing. We have also had the benefit of learning from some of the mistakes of the Internet’s evolution, and have included guidance on appropriate security, data sovereignty, and controlled interchange of data.

INDUSTRY EVOLUTION

US Automotive companies have relied on real-time data to improve plant productivity for several decades. These efforts were supported by Industry 3.0 technology that leveraged Programmable Logic Controllers (PLC's) and locally hosted applications to automate production and quality. Most of these applications are still in place. A review of the technical challenges they represent is important to understanding how to architect for the future.

Siloed Information

Legacy Plant floor applications evolved to support lean manufacturing efforts. This resulted in the purchase or development of IT systems that aligned to enterprise level engineering groups within a company. As such, it is very common to see such systems grouped into operational domains: Design, Delivery, Quality, Safety, Cost Management, People, Maintenance, and Environment

Stovepipe Architecture

Vendor Lock-in

Propriety, Closed

No Interoperability

No Application Portability

Data Silos

Difficult to Scale Up or Down

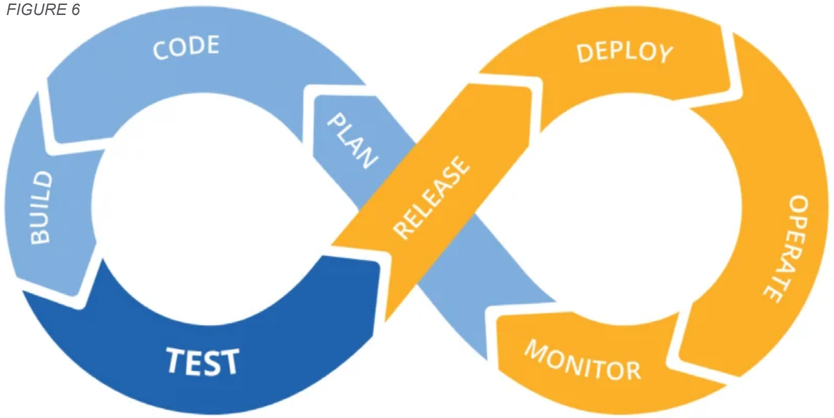
Costly Procurement and Support

The resulting architecture of these built-for-purpose solutions have a ‘stovepipe’ shape with duplicate plant floor device connections, data collection methods, information repositories and application hosts. Companies must engage numerous subject matter experts for the design, implementation, and maintenance of these software applications. If commercial packages are used, multiple vendor relationships and renewal budgets must be managed.

The fact that these systems often connect to the same plant floor device impacts the frequency of upgrades. Most facilities cannot support multiple downtime windows for support. IT departments will coordinate installation of new versions quarterly or annually. This slows their ability to respond to feature requests driven by market pressures.

The availability of capital for system maintenance in the years beyond a new model launch makes support more complicated. It is not uncommon for companies to support multiple versions of the same application based on the date it was first installed. This elevates the risk associated with technological obsolescence and increases the cost of support. As these installations age, so does the likelihood that they will become unsustainable.

FIGURE 6



- Each application has its own ‘stove-pipe’ architecture/technology stack
- Many software vendors have not adopted cloud technology making it difficult to scale solutions from the plant to the enterprise
- Ongoing reliance on physical or virtual IT infrastructure that requires downtime for replacement and limits the ability of IT staff to provide functional support/upgrades
- Custom in-house applications are based on technology that is at the end of its useful life

Source: CESMII - The Smart Manufacturing Institute

Non-Interoperable Software

Built-for-purpose applications are disconnected solutions that house duplicate data that is difficult to share. For example, vehicle sequencing, machine performance and product quality data may all be stored in separate applications. This makes it difficult for plant personnel organized by the physical layout of a plant (Departments, Lines, Teams) to access summary performance views.

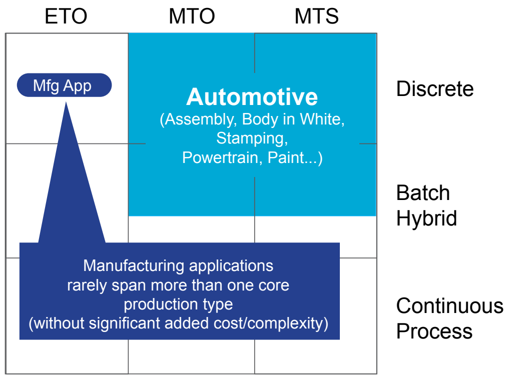
Additionally, companies are incurring additional costs in custom integration points between the systems to provide aggregate data. These efforts can be difficult if enterprise information standards were not enforced or if a commercial package limits the flexibility of the Information Model. This results in costly, brittle integrations and in many cases the continued dependence on manual data exchange.

This reality is anathema to modern software development; in most industries, we see common building blocks, like object orientation, class-extension, and relationship graphs as table stakes. In the manufacturing industry, these primitive capabilities are either missing, or trapped in a proprietary, vendor-specific implementation.

Limited Support for Production Complexity

The manufacturing systems landscape is highly fragmented, with literally hundreds of applications spanning all functional areas across production, quality, and maintenance. Manufacturers have tried to limit the number of applications they select and standardize on, but this has proven to be a challenge. Many ‘Commercial Off-the-Shelf’ (COTS) solutions require significant customization to meet the diverse needs of the different manufacturing operations represented in a typical automotive environment.

FIGURE 7



Source: CESMII - The Smart Manufacturing Institute

CESMII’s analysis has revealed the root causes of this complexity. As illustrated in this diagram, there are nine fundamental production types - with Engineer-to-Order (ETO), Make-to-Order (MTO) and Make-to-Stock (MTS) on one axis, and Discrete, Batch/Hybrid and Continuous Process on the other. Each of these nine production types represents a unique set of production schedule types, bill of material, business processes and workflows. There are distinct automation and control strategies, and there are often significantly unique data contextualization requirements by production type, resulting in the need for distinctive data ingestion strategies and application infrastructure.

This is particularly evident in the fact that almost every (Purdue Model Level 3) manufacturing application is invented in one production type, with data ingestion and contextualization infrastructure designed and optimized specifically for the workflows and processes unique to that type. Inevitably, when that application is implemented in any of the other production types (most automotive operations represent more than one production type, as depicted above), the cost and complexity go up dramatically, and those implementations often stall or fail. It takes significant investment for any application from one production type to effectively work in another production type.

Non-Scalable Architectures

Industry 4.0 includes the ability to ingest large volumes of data and automatically make decisions from it. Existing systems may not support connections to stand alone sensor data and would not support the volume and velocity of its acquisition. *(Figure 8)*

Limited Integration with Supply Chains

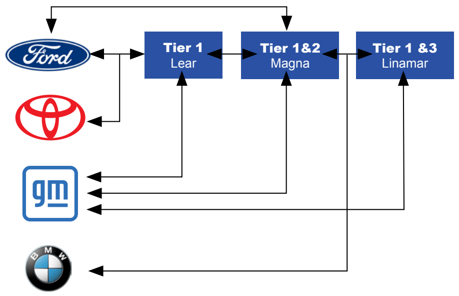
The challenges listed above are commonly associated with the vertical integration of manufacturing systems, and related enterprise asset management and resource planning within an automotive company.

FIGURE 9

Typical Scenario

(Automotive - Broadcast, Sequence)

- Ford uses Lear as a supplier *(seats)*
- Lear uses Magna as a parts supplier *(power seat subassembly)*
- Magna uses Linamar as a supplier *(motor & related assemblies)*
- Ford uses Magna as a supplier *(seats, others)*
- Toyota uses Lear as a supplier *(seats)*

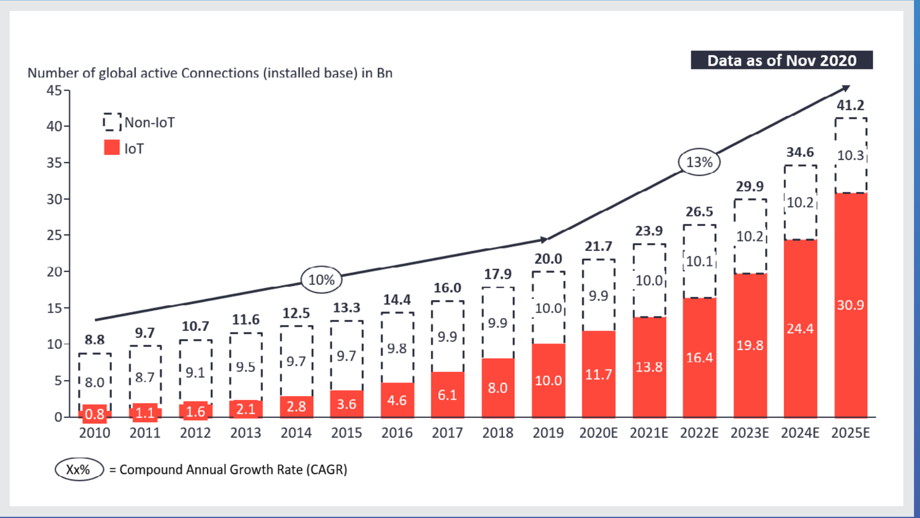


Source(s): CESMII - The Smart Manufacturing Institute

Integration with the value chain beyond the manufacturing plant is typically limited to the broadcast (and some sequencing) messages required during the assembly process. Very little real-time information is available about the capacity or health of supplier facilities or the quality of the parts they deliver. There are no standards for that type of real time data exchange, and the traditional vendor solutions to accommodate that are highly proprietary, costly and in every case, unique to that particular OEM. This has been a major constraint for the OEMs and their Tier Suppliers to establish a more robust, real time data interchange.

Total number of device connections (incl. Non-IoT)
20.0Bn in 2019 - expected to grow 13% to 41.2Bn in 2025

FIGURE 8



Source(s): IoT Analytics – Cellular IoT & LPWA Connectivity Market Tracker 2010-25

Industry 3.0 vs. Industry 4.0 Strategies

The Automotive Vision for Manufacturing Systems aligns closely with the migration from an Industry 3.0 strategy to an Industry 4.0 strategy to better maintain the competitiveness of the US auto industry. The table below provides a comparison of the characteristics of Industry 3.0 and Industry 4.0 based systems.

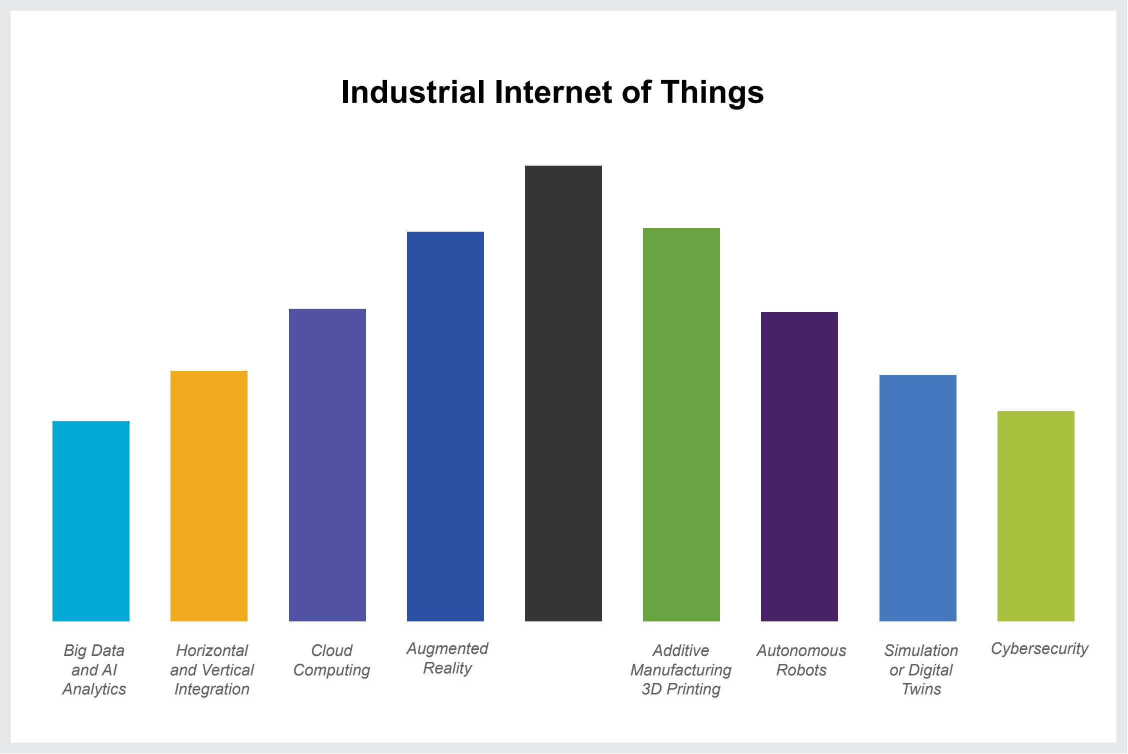
FIGURE 10

Characteristics	Industry 3.0	Industry 4.0
Processes	Automation	Autonomous Decision Making
Industry defining technology	Industrial Robots	Collaborative robots
Production Planning	Demand Forecasting	On-Demand Manufacturing
Alignment	Interconnection of Processes	Interconnection of the whole value chain
Variation	Delimited Variation	Individually unique products
Goal	Efficiency	Flexibility
Base for Revenue	Selling products	Products and Services

Industry 4.0 Technology Pillars

The technology that supports industry 4.0 strategies is based on nine pillars that are gradually being adopted in the US automotive industry. *(Figure 11)* Most manufacturers and suppliers are already leveraging these technologies, but their vertical and horizontal integration is not complete and is hampered by a lack of standards for data exchange.

FIGURE 11



Source: SAP | https://www.sap.com/products/scm/industry-4-0/what-is-industry-4-0.html

Benefits of an Industry 4.0 Ecosystem

The benefits of a modern strategy will be realized when the data that these technologies produce and consume are used to create a complete Information Model of all physical equipment and every event in the production process. The resulting information can be made available to manufacturers and suppliers to support personalized production based on customer pull, and lot sizes as small as one, rather than the market push approach that was used previously. Moreover, by adopting Industry 4.0 standards, we believe compute environments will be safer and more secure, thanks to hyperscale Cloud platforms that are already investing millions more than USCAR can in safety and security of their infrastructure. It's important to note that a common approach to Industry 4.0 does not rule out differentiation or specialization – it's expected that implementations will have uniqueness and include innovation for competitive advantage.

Personalized Customer Experience

- Customized Vehicle Ordering
- Flexible Order Modifications
- Realtime Consumer Awareness of Production Status
- Product Upgrades
- Add/remove Product Service Subscriptions
- Predictive and Preventive vehicle diagnostics

Intelligent Products

- Transparent Location and Time to Delivery
- Realtime Product Health and Remotely Upgradable Product Features

Empowered People

- Real-time Access to Sensor and Analytics Data
- Wearable technology and augmented reality apps to help with problem-solving

Intelligent Equipment

- Autonomous Robots
- Machine to Machine Communication
- Machine to Operator Communication
- In-Station Product Testing
- Predictive/Prescriptive Maintenance

Real-time Traceability

- Real-time Traceability of Materials from Point of Origin to Assembly
  - Specifications
  - Manufacturing Parameters
  - Defects and Consumer Feedback

Expanded OEM Partnerships

- Real-time support and continuous improvement.
- Increased sharing of critical manufacturing data for improved flow

Beyond Industry 4.0

Future efforts build on Industry 4.0 but shift the focus to transitioning industry to be more sustainable, human-centric, and resilient. Although early in this lifecycle, next generation initiatives begin to point to significant evolution of current 4.0 thinking. To truly understand and improve on these metrics, a solid Industry 4.0 foundation that includes interoperability of data across a complete information arc that spans suppliers is a requirement.

AVAILABLE ACCELERATORS

In over 50 funded projects, CESMII's prescriptive guidance to teams is to start with developing the Information Model. While a given problem will have its own model, CESMII provides tools that allow these "component Information Models" to contribute to a larger cohesive graph that results in an organically created Information Model of the "big picture." Many manufacturers must begin by learning what an Information Model is, how to define a Type or Class, and how to design for repeatability. USCAR participants are already familiar with these concepts and have decades of experience in creating "information blocks" within FIS, Quality and Maintenance systems that are intended to be consistent and repeatable. This historical effort accelerates the roadmap – but is not without its challenges.

Based on survey responses, and CESMII's own observations, inconsistency of application, incomplete modeling, and a toolchain assembled from multiple incompatible software packages has created a situation that hampers modernization and constrains sustainable innovation.

The top three priorities identified in survey data all support this hypothesis:

1. Smart application development requires a consistent, modern, and type-aware API layer. Although individual software packages include APIs, each has its own, most are dated, and none are aware of the other.

2. While there are disparate "systems of record" for specific problem areas, there is no federated view that models information across all the systems. More than a "Unified Namespace", this federation layer must persist a graph that maintains links and relationships across all data sources and expands across supply chain participants.

3. Innovation requires the ability to try new tools, "fail fast" on pilots, and generate iterative data science – this is impossible without interoperability amongst data producers and consumers. Unless a single toolchain emerges that can solve all problems, the industries' best chance for interoperability is in the exchange of data; in reliable, predictable, persistent, and secured instantiations of component Information Models.

This does not mean that existing systems are "throw-away" however! Some of the tools in place already implement some of these concepts. FIS Event Blocks, if consistently applied, are small component Information Models, that suggest graph relationships to asset Information Models. Existing efforts to model assets and relationships inform a graph of a site or enterprise. These are assets in creating a roadmap, and while they are likely to mature or be refactored, will accelerate efforts to create common Information Models.

The SAE/USCAR effort to standardize machine data structures is a laudable step in the right direction, creating a reliable interface for portions of the data useful for Smart Manufacturing. Recommendations for that effort include a programmatically enforceable articulation (such as those provided by Smart Manufacturing Profiles[1]), leveraging previously published standards, expanding the types of data to be standardized, and contextualizing the machine data properly in a larger (graph-based) Information Model.

Of the strategies CESMII presented on the survey, response data indicates a medium priority (with high standard deviation) for a topic called "Dynamic Asset Configuration." It seems likely that there is a mixed understanding of the power of this strategy – a better term may have been "automatic asset configuration." CESMII's research and project effort to date indicates that when assets (generally, any producer of data) self-identify and present their on-board component Information Model, Smart Manufacturing platforms can more rapidly ingest those assets into the overall Information Model, and analytic and machine learning tools can more easily identify features and relationships in data models. Recommendations in this roadmap include an emphasis on creating, or influencing the creation of, data sources that include a mechanism for automatic configuration. This approach is a part of CESMII's Smart Manufacturing Profile effort and has analog and compliment in the Industrie 4.0 Asset Administration Shell technology. Most USCAR participants have already put effort into asset standardization that can be easily leveraged in accelerating the presented roadmap.

1 See Appendix A

SUPPORTING TECHNOLOGIES

Numerous technologies form the building blocks for a Smart Manufacturing solution. The adoption of advanced sensors, controls, platforms, and modeling (ASCPM) will radically improve productivity, precision, performance, and energy consumption.

Ensuring Technology Reusability

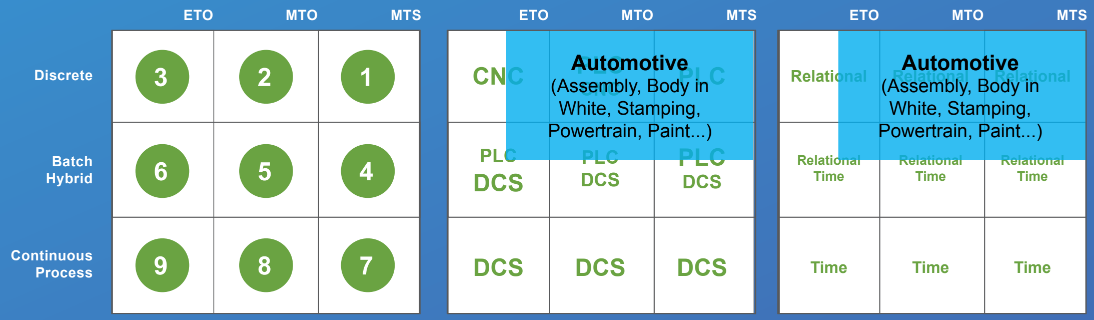
In an integrated Industry 4.0 ecosystem, all data is transferred and collected against an agreed upon industry (or de facto) standard. The standards support the profiles of common industrial equipment and the process events associated with unit production. There is a shared understanding among users of the data about its source, meaning and quality.

Published standards exist to guide the production and consumption of persistent, context-rich data within the organization. Processes exist to convey these standards to part suppliers, machine builders, application developers and company staff. The interoperability standards ensure that systems work together and not in silos and that data flow is seamless and self-aware.

Requirements for a Next Generation, Information Model-Driven Architecture Build or Buy…

- Designed as an interoperable, cloud native and cloud agnostic manufacturing platform
- Designed to support all nine production types (MTS, MTO, ETO – D, BH, CP)
- Architected with 3 layers (OPEN SPECIFICATIONS) to eliminate stovepipe architectures and ensure application portability
  - Open source modern GraphQL API to support discovery of plant model, equipment instances, ingestion of both real-time and historical data by best of breed SM applications
  - Support the use of industry standard SM Profiles™ to build a plant model
  - Open API Edge layer to support ingestion into SM Profiles from various protocols and historians
- Supports hierarchical and non-hierarchical structures (graph-based)
- Supports all data types, structured and unstructured (esp. relational and time-series)
- Simple to administer and support (configure vs. code)
- Scales well from small site to a large enterprise and supply chain
- Supports a true Supply View beyond the four walls of any single plant
  - The model can organize and manage information between plants within an enterprise
  - The model can extend across Supply Chain tiers, connecting disparate data into a unified view

FIGURE 12



Source: CESMII - The Smart Manufacturing Institute

Interoperability Maturity

Future Smart Manufacturing systems need to leverage three levels of interoperability:

Technical interoperability

The ability to use a physical communications infrastructure to transport data is vital. This includes the use of industry accepted standards such as OPC UA/MQTT, and others.

Syntactic interoperability

This defines a shared syntax or common Information Model. Just because systems can interact with each other on a technical level, interoperability fails if the model methodology or communication payloads (data packets) are not defined and adhered to.

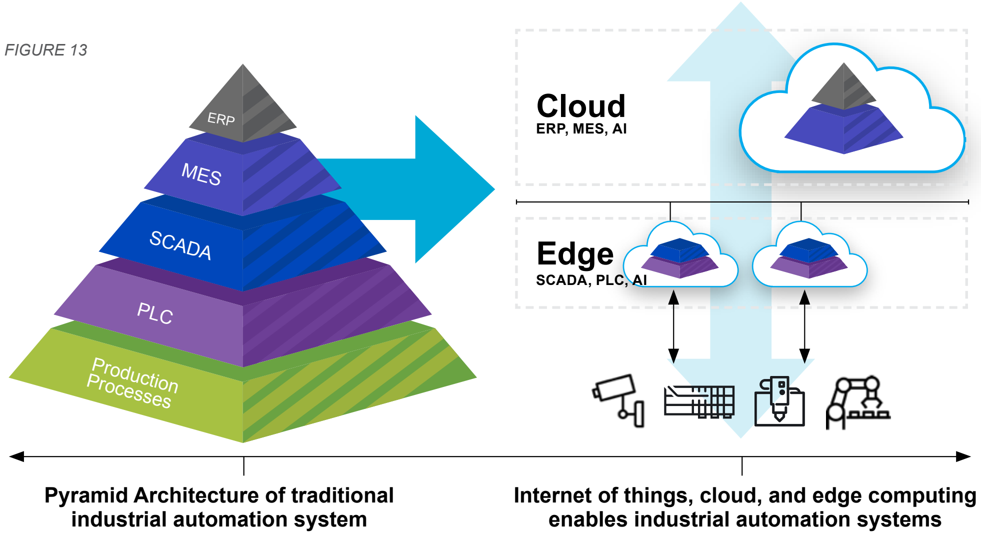
Semantic interoperability

IoT deployments require the ability to establish the meaning of the data. From a technical perspective, manufacturers may be utilizing OPC UA or MQTT with a data model that includes definitions, but the details are in the semantics. A simple example of this is "a part count" tag. That definition is incomplete as it could mean a part count excluding scrap parts, a part count with trial parts, etc. It might be a count that resets at the beginning of the shift, or a free running counter. Semantic interoperability requires agreed upon terms to avoid ambiguity.

Graph Models

Anecdotal evidence, and documented USCAR efforts discovered during the creation of this roadmap, suggest an increasing maturity of thinking regarding individual data sources. However, these have not indicated a thorough realization of the pressing need for a larger aggregate Information Model.

FIGURE 13



Source: MDPI

Research and implementations performed by CESMII over the past 5+ years clearly illustrates the need for Information Models that span multiple data sources. In the past, manufacturing technology has looked at these relationships as primarily hierarchical – standards such as ISA-95 strictly define these hierarchies as being predominantly topological. Modern information analysis requires the ability to discover and capture non-hierarchical relationship. Machines are not just physically related, they are also interrelated through energy, vibration, human operators, network connections, etc. These relationships must be captured in order to be analyzed. Similarly, supply chain participants have fluid relationships that change based on market demand. Finished products have relationships with parts, materials, operators, and environmental factors. A Graph Information Model allows for the articulation of these relationships, making them explicitly and programmatically discoverable for analytic tools and smart applications.

Technology Definitions

This roadmap will highlight technologies that may, or must, be leveraged in a modern Smart Manufacturing effort. While the related dialog briefly describes the technology and its application, Appendix A includes more detailed explanations that may be useful.

RISKS AND MITIGATION STRATEGIES

Throughout the development of this USCAR Automotive Roadmap document, we have discussed many risks which are facing the Automotive landscape.

In relation to this document, we have distilled this down to the top five risks. In the end, if the following risks are not mitigated, there will be a negative impact to each business in the areas of operational costs, quality, sustainability, supply chain and people management:

	Risk	Mitigation Actions
1	A slow evolution from Industry 3.0 to Industry 4.0, or a “if it ain’t broke, don’t fix it” approach, will leave USCAR members struggling to compete in the near future.	• Create cross-function IT/OT teams. Make sure they have a voice • Adopt many of the roadmap principles in this document
2	Fractured architectures, with data spread across closed-ecosystem silos limits agility, analysis and innovation.	• Develop Common Automotive MES Information Model and a common platform • Share across industry – Quality, FIS, Maintenance • Setup a cross industry technology group – publish and standardize across USCAR • Push down to machine builders and Tier 1 and Tier 2 suppliers
3	Legacy, or emerging “home grown” internal approaches that are not standards-based limit interoperability and slow innovation.	• Engage with industry consortia to understand and implement established and emerging standards where-appropriate • Participate in consortia and standards working groups to influence new standards to USCAR’s benefit
4	Failure to standardize data and capture relationships programmatically prevents harnessing AI, ML and predictive analytics.	• Define standards-based Information Models • Capture relationships in an information graph • Start small POC projects – validate small wins and create momentum on specific use cases. • Expand as success grows across plants / enterprise
5	Knowledge-transfer to a next generation workforce is partial or incomplete, modern technologies to fill the gap aren’t deployed.	• Invest now in developing the workforce and meeting them with contemporary technology. • Next generation workers expect information to drive corrective actions therefore information must be sent to mobile devices with closed loop actions and KPIs. • Consider all aspects of people, process and technologies

GUIDING PRINCIPLES OF THE CESMII ROADMAP STRATEGY

The concept of Smart Manufacturing has been evolving for a decade among leading manufacturers, expert practitioners, and consortia organizations like CESMII–the U.S. Smart Manufacturing Institute.

Along the way, ideas that sound similar have emerged but have lacked clarity in terminology, definition, and goals. The industry now needs to agree on a set of guiding principles to accelerate the next phase—the democratization of Smart Manufacturing.

To democratize innovation, it is necessary to disseminate the technology and the knowledge required to implement the solutions and strategies. CESMII is working on both dimensions and recently published an updated definition and guiding principles for Smart Manufacturing as a foundation for the work ahead.

First Principles

CESMII defines Smart Manufacturing as the information-driven, event-driven, efficient, and collaborative orchestration of business, physical and digital processes within plants and across the value chain.
In Smart Manufacturing, organizations, people, and technology collaborate constructively via processes and technology-based solutions that implement seven first principles:

Open and Interoperable

Openness and interoperability in Smart Manufacturing empower a connected ecosystem of devices, systems, people, services, and partners communicating in a natural yet structured manner. Smart Manufacturing works across on-premises, edge and cloud computing platforms, exchanging information in a collaborative ecosystem with broad adoption of machine-to-machine (M2M), application-to-application (A2A), and business-to-business (B2B) integration standards and APIs that enable multi-vendor hardware and software plug-and-play solutions.

Sustainable and Energy Efficient

Smart Manufacturing drives sustainable manufacturing of products through processes and systems that optimize use of resources, minimize negative environmental impacts, and maximize positive socio-economic impacts. Smart Manufacturing optimizes the use of energy as a direct ingredient, instead of treating it as overhead, and contributes to a circular product lifecycle by facilitating information for reuse, remanufacturing, and recycling scenarios.

Secure

Smart Manufacturing provides broad, secure connectivity among devices, processes, people, and businesses in the ecosystem, securing data integrity, protecting intellectual property, shielding against cyberattacks, and maintaining business continuity with minimal impact to performance of the overall network of networks. Security starts with zero-trust approaches for every “thing” in the ecosystem, implementing schemes for access control, data traffic monitoring, fault-tolerance, high availability, anomaly detection, issue containment, and seamless data recovery.

Scalable

Smart Manufacturing scales across all functions, facilities and the entire value chain with cost and performance growing linearly—instead of exponentially—as load and complexities increase. Systems, components, and resources are added, modified, replaced, or removed with ease to accommodate changing demands. Smart Manufacturing is democratized for adoption by the entire value chain, including smaller manufacturing suppliers.

Resilient and Orchestrated

Smart Manufacturing adapts to schedule and product changes with minimal intervention, easy reconfiguration, and optimized process and material flows. Smart Manufacturing is quick to react to changes in demand, resilient to disruption and capable of maintaining business continuity through adaptability, modularity, and minimal redundancy. A Smart Manufacturing ecosystem leverages collaborative decision-making and orchestration to get the right product to the right place at the right time.

Flat and Realtime

In Smart Manufacturing, resources and processes are digitally integrated, monitored, and continuously evaluated based on all available contextual information to support near real-time, informed decision making. Near real-time means: 1) event driven – rather than waiting on periodic updates, and 2) as close to real-time as possible where needed. The information flow across the enterprise and value chain is flattened, enabling more autonomy and faster decentralized decisions with enhanced visualization of information, metrics, and analytics.

Proactive and Semi-autonomous

Smart Manufacturing moves beyond static dashboards and reporting practices to proactive and semi-autonomous processes that act on near real-time information. Automated, predictive analyses trigger automated decisions on routine situations and alert employees to act on non-routine situations with prescriptive recommendations. Predictive and prescriptive software techniques leverage digital versions of physical products, equipment, and processes, including simulations and mathematical models.

Provenance

Accurate data about exactly what materials and parts go into a vehicle is key to several of the pillars of this document. It is required for the “Customer Experience”, “Sustainability” and resilience themes. Provenance is distinct from traceability in that it includes the genealogy of materials, which records costs, environmental impact and quality data persisted and retrievable historically.

ROADMAP

What got us here won't get us there sums up the challenge facing the auto industry today.

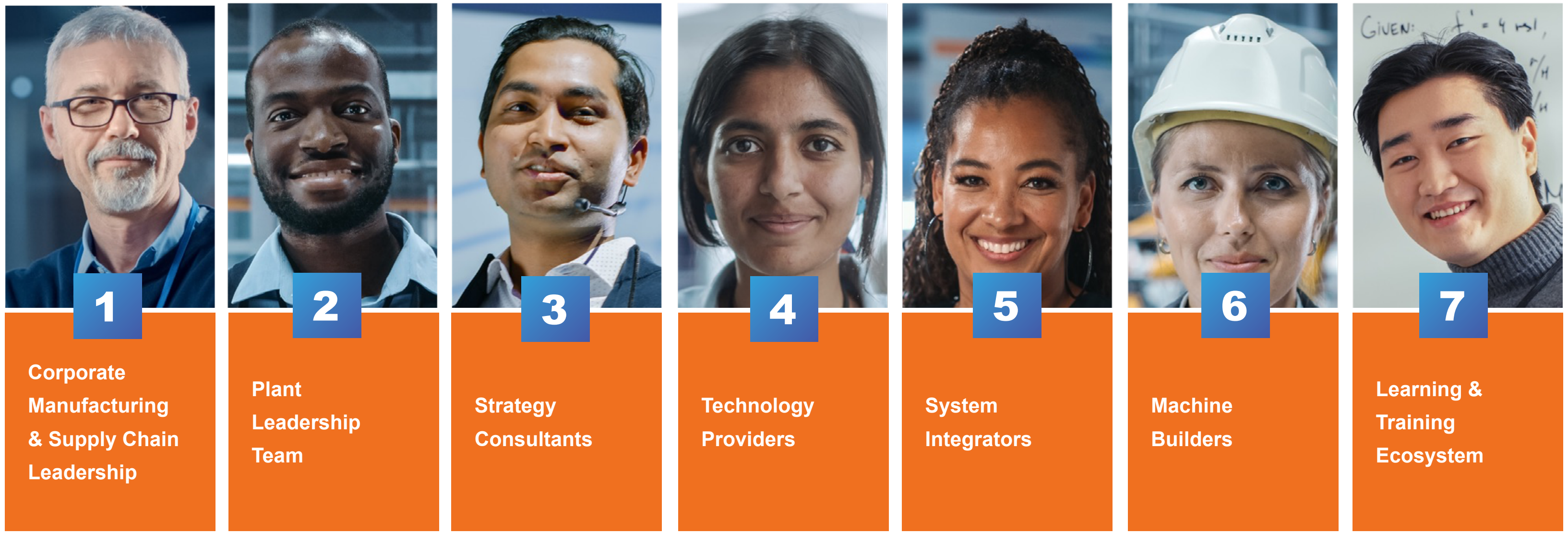
The fast-changing design of the automobile, the move to EV platforms, and the competitive pressure of a massive supply network – these linked issues demand a different approach for automobile manufacturers and their suppliers.

The business case for change is compelling. Reductions in time to market, increased productivity, increased line flexibility, resource optimization (human and equipment), real-time collaboration and interoperability with supply chain partners are all opportunity areas for large gains. (Deloitte estimates at least 15% savings potential)

Essential Roadmap Objectives

In order for USCAR to realize the value of Smart Manufacturing, it's important for all relevant (internal and external) stakeholders to understand their role in this transformation journey. Seven stakeholder groups have been identified as essential for Smart Manufacturing success, and the following are the core strategies and behaviors – the SM Mindset – for each of them:

FIGURE 14



Source: CESMII - The Smart Manufacturing Institute

1

Corporate Manufacturing & Supply Chain Leadership

- **Develop a Smart Manufacturing mindset and culture,** with a commitment to a long-term vision, strategy, funding model, and the organizational structure that align re-sources and people for SM success
  - Create Smart Manufacturing Executive roles to drive SM mindset and influence business strategy
  - Create a corporate Smart Manufacturing strategy and long-term funding model – in partnership with each plant (3+yrs)
- **Tie Smart Manufacturing to existing strategic initiatives** including Supply Chain Resilience, Sustainability and ESG, etc.
- **Develop organizational structures and capabilities** that empower people for SM success. This includes creating direct alignment between continuous improvement initiatives and digital/manufacturing IT teams
  - Work/Tasks reimagined and designed with digital capabilities
  - Focus on plant and frontline leaders to ensure continuity in mindset, messaging and strategic commitment
- **Create holistic education and training strategies for all key stakeholders** in the business and the plants to develop people with the skills needed to accelerate Smart Manufacturing and create data driven cultures
  - Expand workforce strategy into the pipeline of future workers by engaging academia and the community
- **Take a proactive role in driving these SM capabilities** into the supply base and respective ecosystems
- **Ensure that all future machine acquisitions require full conformance** to industry-standard Information Models
- **Ensure that all future manufacturing software acquisitions** exclude proprietary, protective and legacy methodologies and only include systems that are based on open, interoperable and non-proprietary interfaces
- **Expect more from strategic consulting engagements,** where financial strategy, justification models, enterprise IT and Plant Operations are all at the table to improve the probability of success
- **Encourage strong partnerships** between Enterprise and Plant technology providers – for both IT and OT

2

Plant Leadership Team

- **Develop a collaborative and sustainable SM funding model** sponsored and driven by corporate leaders
- **Build equity in,** and support the rollout of a Smart Manufacturing Mindset
- **Develop organizational alignment** that compels Lean/CI and Digital teams to collaborate
- **Ensure** local Smart Manufacturing and productivity initiatives are linked to plant and corporate Sustainability and ESG targets
- **Make automation, networking standards, Information Models and connecting equipment a priority**
    - All equipment purchased must have connectivity, data availability, and at least a base Information Model that adheres to both corporate conventions, and open and interoperable industry standards
    - All equipment purchased must incorporate Smart Manufacturing requirements in “Equipment Technical Data Packages”
- **Train the workforce** on how to use digital capabilities for agility and responsiveness in manufacturing operations, and extend digital capabilities into the process of attracting, developing and retaining the workforce
- **Evolve new hire onboarding process** to take advantage of new learning capabilities
- **Expand workforce strategy** into the pipeline of future workers by engaging academia and the community
- **Expect and require** plant vendor ecosystem to engage with corporate leadership

3

Strategy Consultants

- **Understand organization’s digital roadmap** – holistically. And/or help create one.
- **Become certified** in Smart Manufacturing
- **Become equipped** to accelerate and propagate the adoption of the Smart Manufacturing Mindset
- **Become familiar with Plant Operations,** and the ecosystem that sustains them
- **Help break the mindset of solution silos** and embrace a unified culture/mindset and a unified digital architecture
- **Help organization reimagine** work and worker tasks in a digital future
- **Come to the table with a sense of urgency** to engage in solutions that are realistic, affordable and sustainable. This is a journey that involves both sprints and marathons

4

Technology Providers

- **Develop strategic partnerships with Technology Providers** that are investing in application interoperability and portability, and that are supporting the journey to a Smart Manufacturing Mindset:
    - Apps built on a rich, open API that supports object and relationship discovery
    - Apps that abstract the application layer from data storage and device communication infrastructure
- **Develop strategic partnerships with Technology Providers** that are investing in an object-oriented, Graph-aware platform that:
    - Provides Type-safety, and graph relationships between instance objects
    - Supports Types defined using Industry Standards (aka: SM Profile)
- **Proprietary, stovepipe architectures, data silos and vendor lock-in strategies** are not acceptable
- **Proprietary, closed networks, protocols, data access,** etc. are not acceptable
- **Develop shared risk business models** for quick adoption and wins
- **Inform training and education providers on knowledge and skills needed** in technology domains so they can be best equipped to deliver on collective needs (don't expect this to come from Technology Providers)
- **Join CESMII in advocating for interoperability and open architectures**

5

System Integrators

- **Partner with SIs** that employ a modern and informed approach to information systems as well as control systems. Qualified SIs will:
    - Understand and can contribute to an organization's Smart Manufacturing strategy
    - Understand the value of interoperability, and of portable, reusable Information Models
    - Contribute to industry initiatives that support interoperability and openness
    - Create, extend and employ industry standard libraries of crowd-sourced Type Definitions and SM Profiles
    - Understand the value of, and can engage in architecting, implementing and developing contemporary, interoperable SM Apps™
- **Partner with SIs** that help avoid 'Shadow IT' systems
- **Partner with SIs** that help avoid stovepipe architectures and solutions
- **Identify and invest in SIs that support the democratization of Smart Manufacturing,** and provide capabilities through modern apps, or implement 'Low or No-Code' solutions

6

Machine Builders

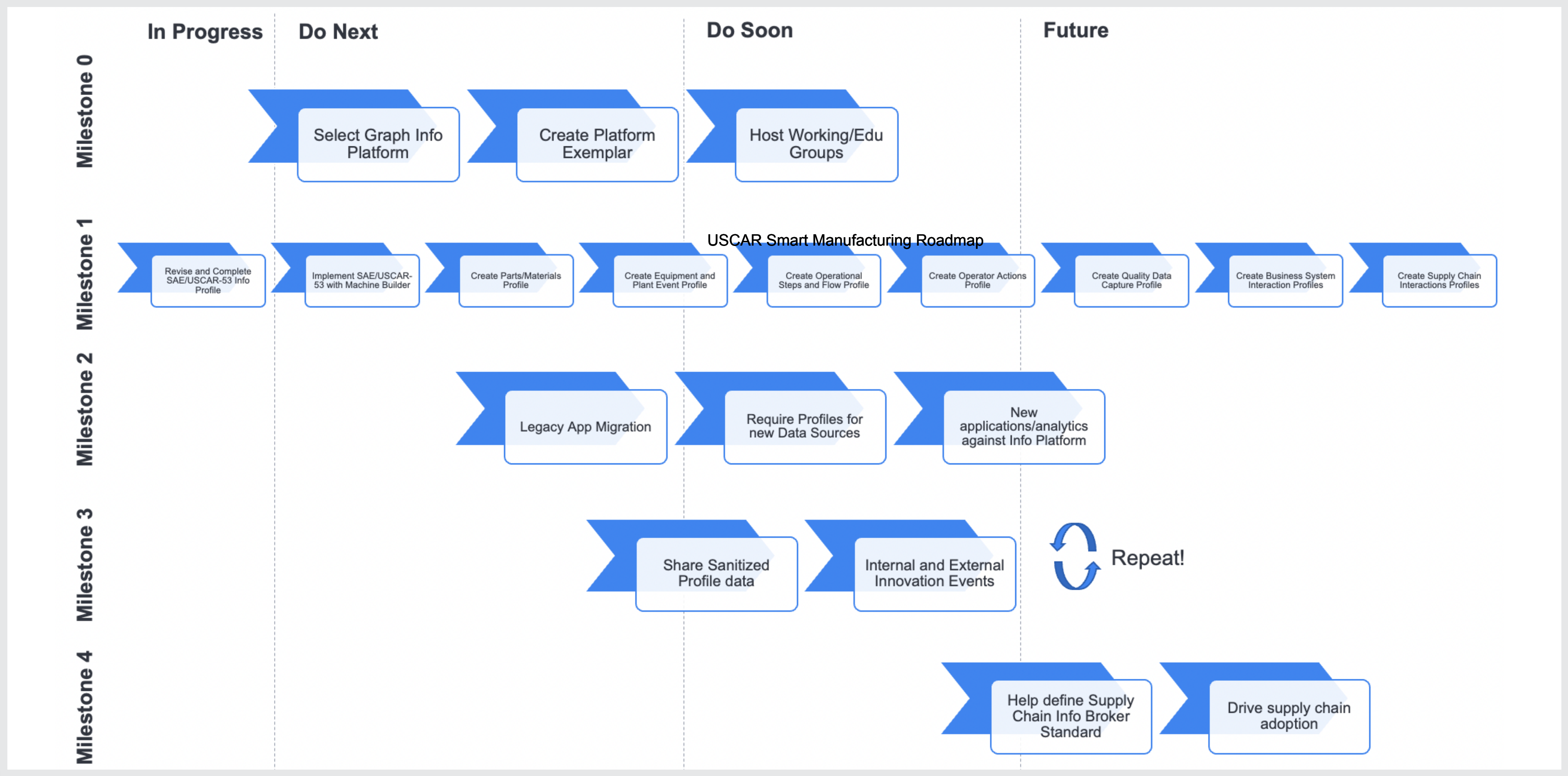
- **Partner with Machine Builders** that ensure all equipment will support object and relationship discovery, abstracting the application layer from both data storage and device communication infrastructure
- **Partner with Machine Builders** that ensure all equipment will support the integration of industry standard data structures (Types)
    - Types are defined using Industry Standards (aka: SM Profiles)
- **Partner with Machine Builders that are engaging in the development of industry standardization** efforts to create and evolve/extend equipment and process Information Models, resulting in:
    - Standard Profiles (publicly available on the SM Marketplace™)
    - Standard Profiles + Extensions (made publicly available via the SM Marketplace)
    - Standard Profiles + Private Extensions (made available only to sanctioned, private parties)
    - Private Profiles (made available only to sanctioned, private parties)

7

Learning & Training Ecosystem

- **Advance the science of AI/ML** for Supply Chain and Manufacturing use cases
- **Identify and create ways to engage youth (k-12)** in developing interests and stackable skills needed to advance SM
- **Develop partnerships** with key manufacturers and/ or industry to have real world data sets
- **Incorporate design thinking** for application-based use cases of education and training methods for accessibility, scalability and impact
- **Encourage educators, non-profits, government and workforce organizations** to provide collaborative training to best serve industrial needs
- **Develop vendor-agnostic courses,** curriculum and manufacturing labs for students to learn and experience open, interoperable manufacturing technologies, architectures and implementation methodologies
- **Work with CESMII to Develop SM curriculum/degree/certification programs**

2023 USCAR Roadmap for Automotive Smart Manufacturing Milestones



SPECIFIC ROADMAP TACTICS

Milestone 0
Establish Information Model Platform

While collecting inputs for this roadmap, CESMII was unable to identify the presence of, or plan for, a common Information Model Platform that persists Profiles (Types), Instance Objects, Graph Relationships, and data. Each USCAR member should review their existing architectures to evaluate their current implementations against the ideal set below...

✔ **USCAR participants must select and implement a modern Graph Information Model Platform (or create an expert team to build one)**

A Platform with these capabilities is relatively new in the manufacturing sector. Existing information tools within USCAR participants cannot provide this feature-set. Specifically, the Information Model Platform must be aware-of Information Profiles, enforce those Profiles programmatically in instance objects, allow the identification and expression of both hierarchical and non-hierarchical relationships, and broker Type-safe access to this data in a secure and modern fashion. Requirements include:

- Design as an interoperable, cloud native and cloud agnostic manufacturing platform
- Design to support all nine production types (MTS, MTO, ETO – Discrete, Batch/Hybrid, Continuous Process)
- Architect with 3 (open specification) layers to eliminate stovepipe architectures and ensure application portability and interoperability
- Provide an open and modern graph API to support discovery of plant model, equipment instances, and ingestion of both real-time and historical data by best of breed SM applications
- Support the use of industry standard SM Profiles to build a plant model
- Provide an open Edge layer to support ingestion into SM Profiles from various protocols and historians
- Support hierarchical and non-hierarchical structures (graph-based)
- Support all data types, structured and unstructured (esp. relational and time-series)
- Simple to administer and support (configure vs. code)
- Scale well from small site to a large enterprise and supply chain
- Support a true Supply View beyond the four walls of any single plant
- A model that can organize and manage information between plants within an enterprise
- A model that can extend across Supply Chain tiers, connecting disparate data into a unified view

CESMII's SM Innovation Platform™ (SMIP™) provides a standards-based implementation of these capabilities. More details about the can be found in Appendix A.

Select and implement a Graph Information Model Platform

Milestone 1
Component-Level Information Modeling

A comprehensive Information Model is greater than the sum of its parts – but it must include parts! Such parts should be common, standardized, and enforceable, without being overly rigid or unable to evolve. CESMII recommends a thorough exercise in modeling information components before taking any other steps.

Revise and complete SAE/USCAR-53 to standardize Machine Data and implement as a programmatically-enforceable Profile

This effort is an important first step in creating a common "Profile" for Machine Data, but in its current form presents some challenges. A human-readable document will always be subject to human interpretation during implementation. A machine-readable format, such as specified by the Smart Manufacturing Profile, can be leveraged to programmatically enforce implementations. MQTT by itself does not enforce standards, and often results in wildly varying implementations.

This, and other, internal standards should be harmonized with, and validated against, existing open standards from industry groups – internal efforts must not re-invent the wheel. Leverage CESMII's interaction with international standards groups.

Information Models evolve. Modern technologies support interface versioning, following conventions of extension and deprecation, rather than breaking changes.

Work with CESMII to define SAE/USCAR-53 as a standards-based Profile to maximize interoperability

SAE/USCAR-53 Profile Implementation with Machine Builder partners

Modern equipment should ship with an information source that implements the standards for Machine Data. In consumer IOT, expectations include access to data; Industrial IOT should be no different. Select one or more Machine Builders to create, or augment, machines to include a data connection (such as an OPC UA Server or Publisher) that implements the USCAR standard.

Work with Machine Builders to create equipment with a built-in information server that implements SAE/USCAR-53

Start similar Profiling efforts for other data sets and domains

All common information sets should be Profiled and standardized internally, rationalized against open standards, and exposed at the source. Candidates for similar standardization of data structures and members include:

- Parts and materials
- Equipment and plant-level events
- Operational steps and flow
- Operator actions
- Quality data capture
- Business System interactions
- Supply Chain interactions

Work with standards-bodies and industry consortia to develop additional component information models

Milestone 2
Graph-Level Information Modeling

USCAR participants must attach Information Model instance data (objects) to a persistent Graph model, with access to current and historical data, that can broker authorized connections to, and operations against, the data and relationships in that data.

Begin migrating legacy applications to the Information Model Platform

Where possible, existing "stovepipe" applications should be abstracted from their integrated data stores or sources and placed atop the Information Model Platform – consuming data from, and returning data to, the common store. While this does not solve the challenges of managing multiple solutions, it begins to establish a common and authoritative system-of-record that applications are beholden to. Legacy applications should be triaged for the criticality and infrastructure brittleness and prioritized for abstraction – or replacement in their entirety.

Migrate legacy applications to selected Graph Information Model Platform

Require all new data sources to come with a Profile and expose data to the Information Model Platform

The Information Model Platform often will be responsible for storing either the data, or an external pointer to all data fit to a Profile. New information assets must arrive with a base Profile describing their data, future assets must have a way to make that data available to the common model as an instance object of the Profile. Implementers and System Integrators should be required to use the Information Model Platform to establish and capture the relationships between incoming and existing data objects.

Require technology providers to submit a standards-based Profile for every new data source

Require technology providers to leverage the Information Model Platform

Key and strategic vendors of legacy software should be encouraged (or sponsored) to adapt their software to modern development practices, consuming Graph APIs from the common Information Model Platform (rather than from source devices, machines or external systems), and publishing data to the same authoritative store.

Require technology providers to build against the API of the Graph Information Model Platform

Milestone 3
Sanctioned Innovation

With a common, authoritative, secure and standards-enforcing Information Model Platform in place, USCAR can begin capitalizing on modern technology through innovation, iteration and information interoperability.

Share Sanitized Profile Data to support Workforce Development and Innovation

Provide access to sanitized instances of common Profile datasets to educational institutes, including guidance on how they are used, allow educators to build curriculum based on the reality of automotive data and applications. Engage with CESMII and its members to help shape that curriculum, so that the incoming workforce is better equipped to support industry evolution.

Publish sanitized datasets to GitHub, University of California Dataset Archive, or other public repository to facilitate innovation and support research in automotive.

Inspire and Sponsor Internal and External Innovation

A sanctioned and secure common Information Model Platform can broker appropriate access to authorized data to innovation teams, data science researchers, modern SIs, and even a next generation of Citizen Developers. Existing capabilities, and new innovations, can be developed as "Apps" of the Information Model Platform that are lightweight, iterable and easily replaced when better solutions are created. Apps can publish Profiles indicating what data they wish to contribute to the common platform, allowing simplified decision-making about what tools should be sanctioned – eliminating the problem of "Shadow IT."

Consider offering a "sanctuary" window where rogue projects can be provided a path to legitimacy through guided porting to a common, properly brokered and secured Information Platform.

Host events specifically to invite and inspire innovation and reconciliation of Shadow IT

Milestone 4
Supply Chain Interoperability

USCAR participants can take leadership position in defining the requirements for modern supply chain participants, advocating for, and sponsoring the implementation of similar milestones through the tiers of suppliers, improving resiliency and agility through section and reliable information interchange.

Help define an interoperable Supply Chain Information Broker

CESMII has proposed to NIST (National Institute of Science and Technology) an implementation of an Information Model Brokering Platform that sits above individual Platform instances and facilitates appropriate and authorized interchange of Supply Chain data. Leveraging the same SM Profile concept, USCAR can help define information sets that can be required from Supply Chain participants to improve real time visibility, birth history/genealogy, and decision-making in product planning and production.

Join CESMII, assign resources to contribute to Supply Chain Working Groups and support research in automotive.

Drive best practices with supply chain partners

Encourage supply chain partners to take on their own initiatives related to Milestones 1-3, foster common information Profiles, maximizing application portability across automotive manufacturing and enabling insight-creating tools to propagate

Require supply chain partners to begin publishing Profiles, or implementing USCAR Profiles.

Mandate that all data sources from supply chain partners be programmatically validated against agreed-upon Profiles. Reject or penalize shipments out of information-compliance.

2023 USCAR Roadmap for Automotive Smart Manufacturing Milestones

Far

Near

Milestone 2 – Graph-Level Information Modeling

- Begin migrating legacy applications to the Information Model Platform
- Require all new data sources to come with a Profile and expose data to the Information Model Platform
- Require technology providers to leverage the Information Model Platform

Milestone 4 – Supply Chain Interoperability

- Help define an interoperable Supply Chain Information Broker
- Drive best practices with supply chain partners
- Require supply chain partners to begin publishing Profiles, or implementing USCAR Profiles

Now

Milestone 0 – Establish Information Model Platform

- USCAR participants BUY or BUILD a modern Graph Information Model Platform
- Establish an Automotive Smart Manufacturing Innovation Center
- Educate the Automotive Smart Manufacturing Ecosystem

Milestone 1 – Component-Level Information Modeling

- Revise and complete SAE/USCAR-53 to standardize Machine Data and implement as a programmatically-enforceable Profile
- SAE/USCAR-53 Profile Implementation with Machine Builder partners
- Start similar Profiling efforts for other data sets and domains

Milestone 3 – Sanctioned Innovation

- Share Sanitized Profile Data to support Workforce Development and Innovation
- Inspire and Sponsor Internal and External Innovation

Interoperable Data Infrastructure | Application Development | Supply Chain

SUMMARY AND CONCLUSIONS

In this roadmap, CESMII has reviewed the challenges faced by the automotive sector due to the evolution of manufacturing technology, categorizing them at three levels: incoherent data sources, incomplete and fractious Information Modeling, and application and analysis architecture not designed for interoperability. The Information Modeling problem is considered the most impactful but least understood by practitioners.

An Information Model describes the available data in a system's context, and it can be applied to various components or participants in a supply chain. However, in manufacturing technology, Information Models are often inferred or constructed after the fact and are held privately by vendors, limiting data and information sharing. The roadmap highlights the power of Information Models in generative AI and the Internet's loose graph of related data.

The symptoms of these problems include siloed information, costly procurement and support, non-interoperable software, limited support for production complexity, non-scalable architectures, and limited integration with supply chains. These issues hinder efficient data sharing, system maintenance, and interoperability between applications.

To overcome these challenges, CESMII has proposed a roadmap for constructing an open, organic, and interpretable Information Model for manufacturing. The roadmap draws from the experience of engaging with manufacturers and learning from past mistakes in the evolution of the Internet. It emphasizes the need for appropriate security, data sovereignty, and controlled data interchange.

The roadmap focuses on three key strategies: connected workforce, modern and flexible IT infrastructure, and a Smart Manufacturing Mindset.

1. The first strategy emphasizes the importance of collaboration and real-time data-driven business orchestration throughout the enterprise and supply chains. The goal is to create flexible and agile processes and supply chains that can easily adapt to changing market demands.

2. The second strategy highlights the need for real-time application and data interoperability based on standardized, open interfaces. This approach aims to eliminate data silos, stovepipe architectures, and vendor lock-in, ultimately reducing costs and improving innovation agility.

3. The third strategy involves developing a Smart Manufacturing Mindset by aligning education, workforce development, and continuous improvement strategies. The goal is to create organizational structures that foster a data-driven culture and promote innovation and collaboration with all key stakeholders.

The roadmap provides essential objectives for various stakeholders in the automotive industry to adopt in order to drive Smart Manufacturing. It outlines specific tactics such as component-level Information Modeling, standardization of machine data, profiling efforts, and partnerships with technology providers, system integrators, and machine builders. It also emphasizes the need for collaboration in the learning and training ecosystem to advance AI/ML for manufacturing and supply chain use cases and develop vendor-agnostic courses and curriculum.

Overall, the roadmap aims to transform the automotive manufacturing industry by embracing Smart Manufacturing principles and leveraging digital technologies to drive efficiency, flexibility, and collaboration throughout the value chain.

APPENDIX A
Supporting Technologies

CESMII Smart Manufacturing Innovation Platform (SMIP)

While an individual technology may on its own be useful in eliminating specific barriers to SM implementation, the information flow between these building blocks is essential to ensure that the solutions developed with these technologies are implemented in a cost effective, re-usable, secure, scalable, and repeatable manner. The SMIP incorporates and implements many of the technologies found in this Appendix.

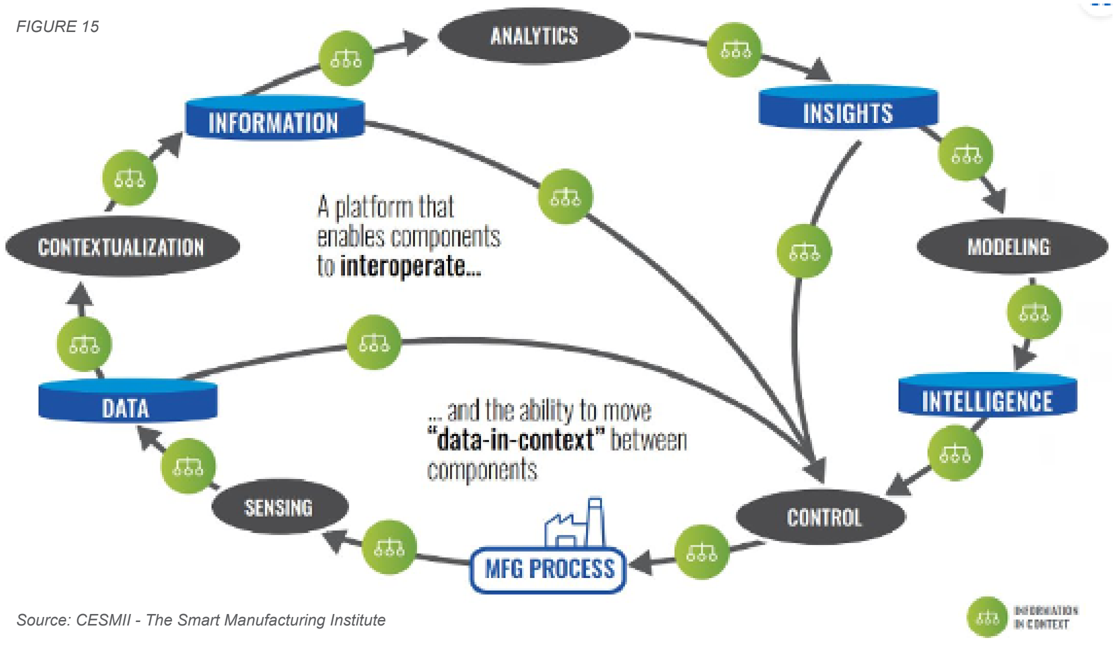
Much of the conversation around Industry 4.0 focuses on the support for plug and play devices and emphasizes the production of data. When the scope of Smart Manufacturing is extended to making applications plug and play the consumption of data becomes the focus. A Smart Manufacturing platform is designed to provide standard interfaces to data that include the real-time status of items available in a unified namespace along with the events, alarms and historical data required to meet the needs of end users.

SMIP Architecture

The SMIP is a combination of strategic technologies useful for organized collection and transmission of manufacturing data, which work together to enable open access to a variety of applications, helping the industry identify constraints, predict challenges, and optimize decision-making and operational orchestration.

The architecture supports many different deployment and scale options, the demarcation between components is as follows:

FIGURE 15



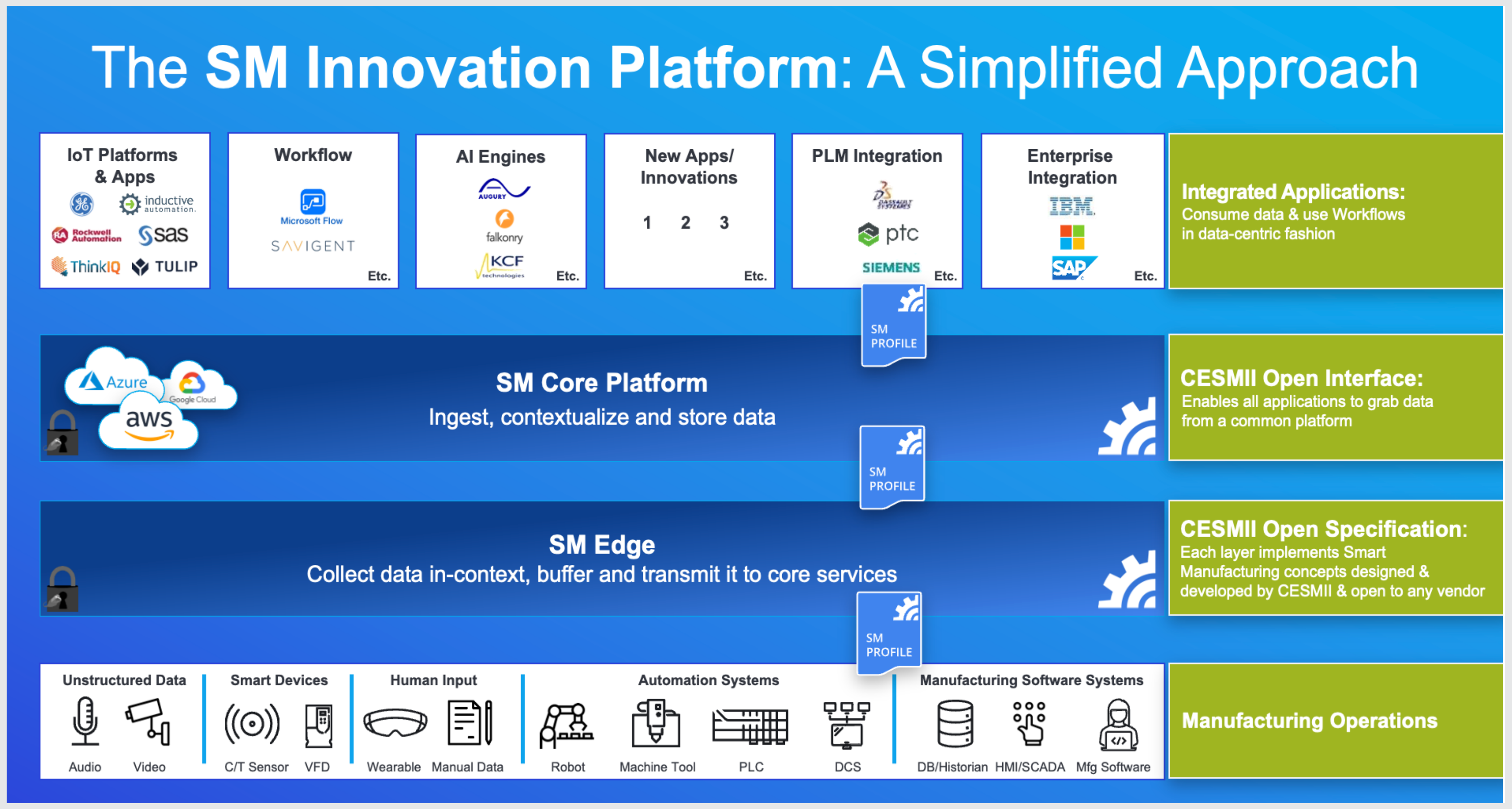
Source: CESMII - The Smart Manufacturing Institute

- The SM Edge™ resides close to the machine or system that is emitting data and is used to collect that data in-context and transmit it to the Core Services.
- Core Services reside in a hyperscale Cloud platform and receive the transmitted data, organize, and store it, and make it available to constituent applications and services.
- The Integrated Applications are consumers of the data, but also augmenters and modifiers, that can work together through Workflow orchestrations in a data-centric fashion.

Smart Manufacturing Innovation Platform

All these components use or benefit from, the Smart Manufacturing Profile – a key enabler to democratizing data access in manufacturing. The SM Profile provides a "decoder ring" for the source equipment or system, a mechanism for establishing and maintaining the intent and context of the data as it flows through the system, and an interface definition language for programmatic access when the data is at rest in an information system.

FIGURE 16

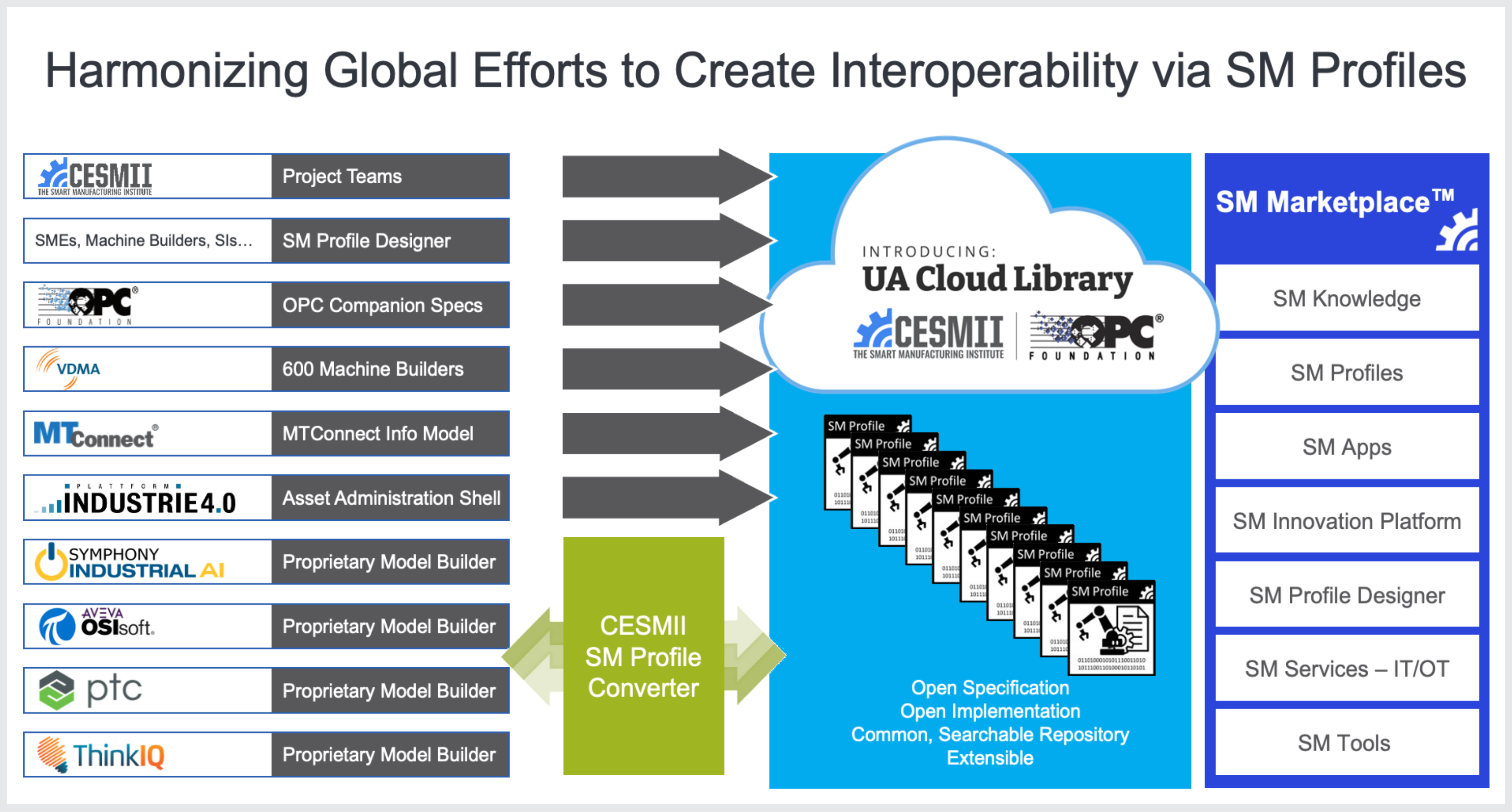


Source: CESMII - The Smart Manufacturing Institute

Smart Manufacturing Profiles

SM Profiles are a standards-based approach to representing structured Information Models that provide the ability to move "data-in-context" from source to consumption, and between components that consume the data to provide a solution. Developers and end-users can adapt or customize the Information Model with constructs that are specific to a particular domain, platform, or application. A profile is a digital extension mechanism to seamlessly connect, collect, analyze, and act at the edge, the cloud and in the apps that connect to the Smart Manufacturing Innovation Platform.

FIGURE 17



Source: CESMII - The Smart Manufacturing Institute

SMIP Capabilities

The core capabilities of the SMIP can be broadly classified into the following:

- Connectivity (ability to connect to different data sources)
- Data ingestion (ability to acquire/capture data)
- Data Contextualization (ability to organize data into a structured form)
- Secure Data access, management, exchange (ability to access, store, retrieve the structured data)
- Workflow orchestration (ability to orchestrate data movement between OT components)
- Interoperability (ability for OT components to access/interact with the structured data)
- Platform management (ability to create instances of the platform for creating solutions)
- Marketplace (ability for applications to be integrated into the platform for use in developing solutions

SMIP Core Services

Built on open standards the SM Core Services are the organization, management and brokering layer of the SM Platform – the literal core where data (or links to external data) are stored and made available. SM Core Services works with Hyper-Scale Cloud providers, such as AWS (Amazon Web Services). Google or Microsoft Azure, which can host executable code that can interact with the SM Core Services. A partial list of capabilities the SM Core Services provides includes:

- A Graph database of structured data, in the form of objects and relationships, that expose, to an authorized consumer (or producer) all data organized by the SMIP.
- An Application Programming Interface (API) that allows for the discovery of data, and type information, for every object stored in the Graph database.
- An Application Programming Interface (API) allows for inserting data not flowing directly up from the plant floor.
- Secure access brokered through an authorization model that allows an administrative user to grant or revoke application and user permissions at a level of granularity that is appropriate for security and safety.
- A User Interface for organization and basic visualization of data as it flows into the SM Core Services. This includes the ability to structure Graph objects and relationships.
- A database for "warm" storage of data useful for visualization, development and run time of applications for visualization, exploration, or prediction of manufacturing data.
- Facilities for instantiation and management of SM Platform resources, including Edge, Core and Apps.

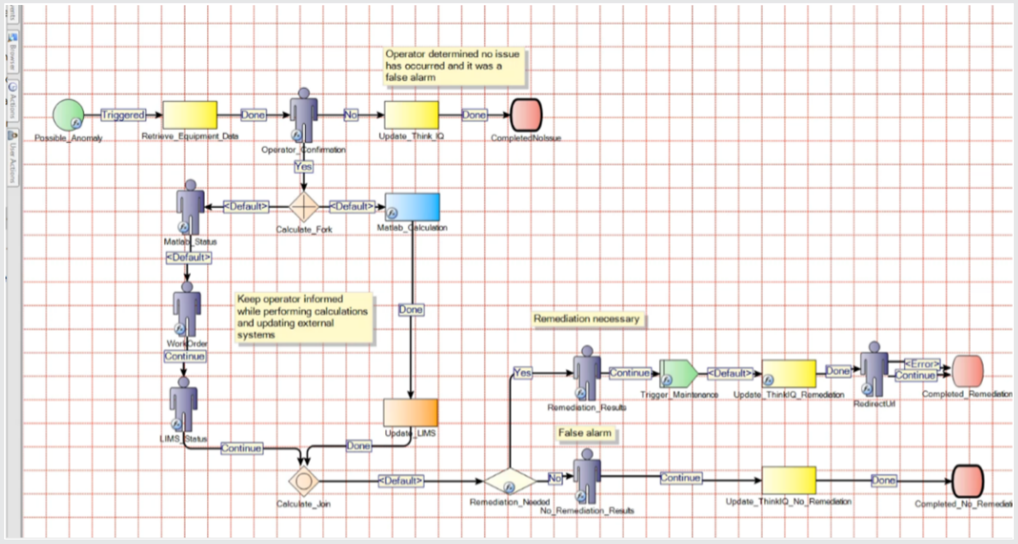
Smart Manufacturing Marketplace, Applications and Orchestration

A vibrant ecosystem of Applications that consume the data produced by the SM Platform is enabled when application developers can de-couple their development from the problem of getting access to data and orchestrate multiple applications toward an industry specific goal. This important orchestration capability is mature and available today, through the SMIP Workflow engine.

The Workflow Engine can consume and respond to data from this Core Services API and use values from that data to invoke sophisticated automated and user actions in response. For example, the Workflow Engine could respond to a raw data value change from any member attribute of object in the Innovation Platform, and evaluate that value to determine if an operator should be directed to take corrective action, an external system should be notified to update the status of a customer order, or a set-point should be changed in a control system – or all of the above, in a specific sequence.

SM Profiles can be linked to common Workflow steps to accelerate deployment. Similarly, Workflows could be attached to apps, such that an energy prediction app could include a Workflow template for maintenance steps useful in optimizing equipment to reduce energy consumption.

FIGURE 18

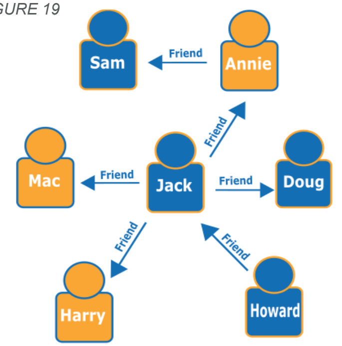


Source: SymphonyAI Industrial

Graph Technologies

Graph databases are purpose-built to store and navigate relationships. Relationships are first-class citizens in graph databases, and most of the value of graph databases is derived from these relationships. Graph databases use nodes to store data entities, and edges to store relationships between entities. An edge always has a start node, end node, type, and direction, and an edge can describe parent-child relationships, actions, ownership, and the like. There is no limit to the number and kind of relationships a node can have.

FIGURE 19



Source: Amazon | https://aws.amazon.com/nosql/graph/

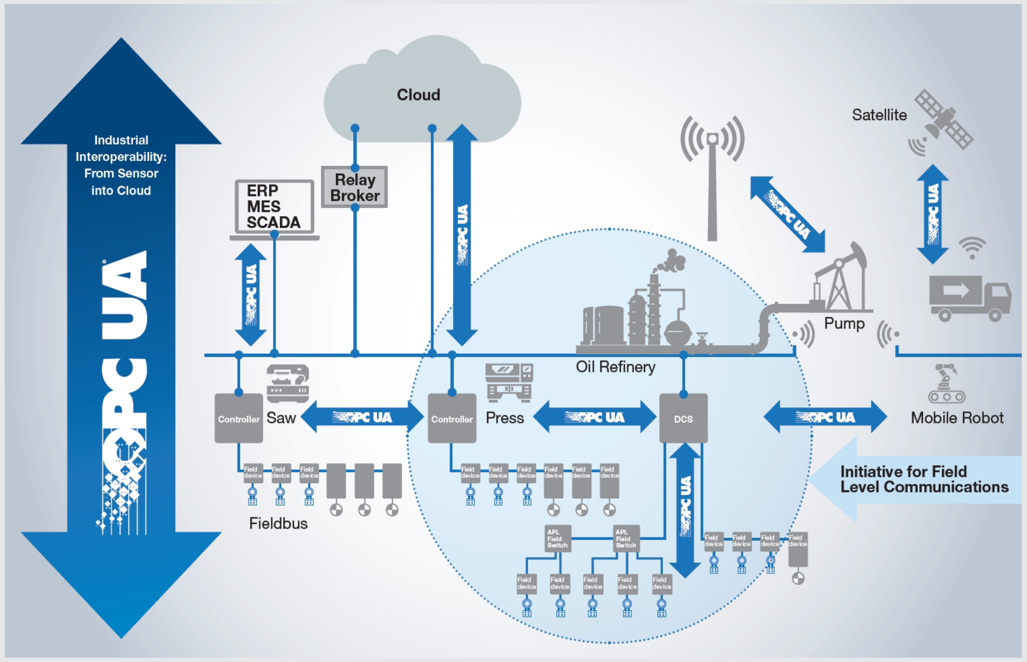
A graph in a graph database can be traversed along specific edge types or across the entire graph. In graph databases, traversing the joins or relationships is very fast because the relationships between nodes are not calculated at query times but are persisted in the database. Graph databases have advantages for use cases such as social networking, recommendation engines, and fraud detection, when analysis needs to understand relationships between data and quickly query these relationships.

Figure 19 shows an example of a social network graph. Given the people (nodes) and their relationships (edges), it is possible to programmatically trace who the "friends of friends" of a particular person are—for example, the friends of Howard's friends.

OPC Unified Architecture (UA)

OPC UA (Unified Architecture) is a communication technology designed to connect enterprise systems (Historians, Analytic Tools, Enterprise Resource Planning etc.) with real-time data from programmable logic controllers, sensors, actuators, and robots that exist in the manufacturing environment. The first version of the specification was released in 2006.

FIGURE 20: OPC UA as standardized communication protocol in Industrial IOT solutions



Source: OPC Foundation | https://opcconnect.opcfoundation.org/2021/09/flc-corner-september-2021/

OPC UA (Open Platform Communications Unified Architecture) is a standard for industrial communication used to provide secure, reliable data exchange between devices and systems in industrial automation and the Internet of Things (IoT).

OPC UA offers key advantages over its OPC Classic predecessor:

- State of the Art Security
- Fault Tolerant Communication
- Cross Platform and Internet Readiness
- Service Oriented Architecture
- Simplified IT Integration
- Sophisticated Information Modeling

OPC UA is not a protocol. It was designed to support data modeling and secure transport of information throughout an enterprise. It can communicate anything from simple device status to large amounts of complex waveform data as part of a plant-wide traceability system. The specification is abstract by design to allow current and future technology to be used for its implementation. IEC 62541 is the current standard for OPC Unified Architecture. It is published as a multi-part specification:

FIGURE 21: OPC UA Specification Parts

ID	Release Date	Title
IEC/TR 62541-1	2016	OPC Unified Architecture – Part 1: Overview and Concepts
IEC/TR 62541-2	2016	OPC Unified Architecture – Part 2: Security Model
IEC 62541-3	2020	OPC Unified Architecture – Part 3: Address Space Model
IEC 62541-4	2020	OPC Unified Architecture – Part 4: Services
IEC 62541-5	2020	OPC Unified Architecture – Part 5: Information Model
IEC 62541-6	2020	OPC Unified Architecture – Part 6: Mappings
IEC 62541-7	2020	OPC Unified Architecture – Part 7: Profiles
IEC 62541-8	2020	OPC Unified Architecture – Part 8: Data Access
IEC 62541-9	2020	OPC Unified Architecture – Part 9: Alarms and Conditions
IEC 62541-10	2020	OPC Unified Architecture – Part 10: Programs
IEC 62541-11	2020	OPC Unified Architecture – Part 11: Historical Access
IEC 62541-12	2020	OPC unified architecture – Part 12: Discovery and global services
IEC 62541-13	2020	OPC Unified Architecture – Part 13: Aggregates
IEC 62541-14	2020	OPC unified architecture – Part 14: Pub Sub
IEC 62541-100	2015	OPC Unified Architecture – Part 100: Device Interface

Source: OPC Foundation | https://opcconnect.opcfoundation.org/2021/09/flc-corner-september-2021/

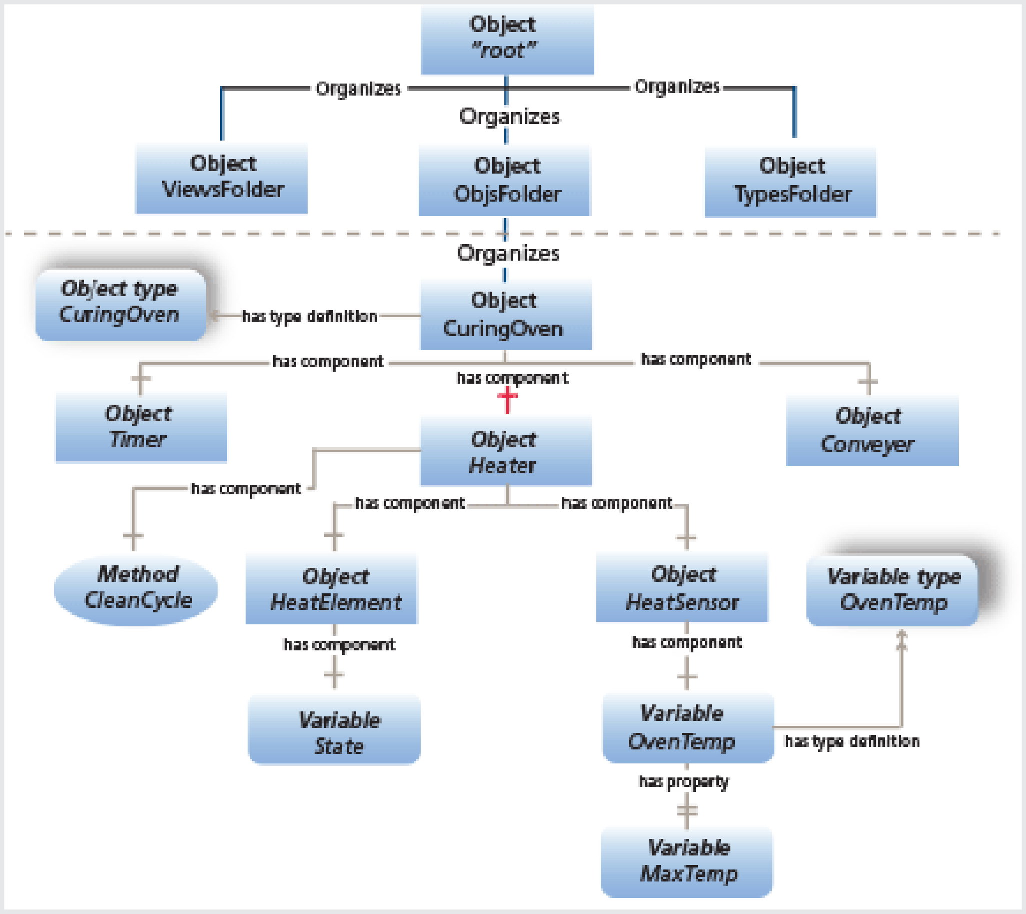
OPC Unified Architecture Information Modeling

Of key interest to CESMII is Part 5, which describes the Information Model. OPC UA modeling refers to the process of designing and creating OPC UA Information Models, which define the structure and data types of the information exchanged between devices and systems using OPC UA. This modeling process involves creating a hierarchical structure of objects and variables and defining the properties and relationships of these objects and variables. The OPC UA Information Model is then used to generate the OPC UA address space, which is the set of addresses used to access the data in the OPC UA server.

The key advantage of OPC UA is its ability to support a complex address space. Legacy PLCs typically supported a flat address space. OPC Classic automation mapped that address to a single tag like “Oven Temperature” and returned its value. The OPC UA address space supports the meta data associated with the value as well. For example, it could hold the unit of measure for temperature, alarm set points for the value, a classification of the sensor type, its hierarchical relationship in a plant according to ISA-95, its manufacturer, and a link to the support manual for the device. This supporting structure transforms the data into meaningful information.

Part 5 of the specification is the fundamental piece of the architecture that allows for open-source Information Modeling. Its object-oriented design has a base element called a node that supports attributes and references to other nodes.

FIGURE 22: Sample OPC UA Information Model

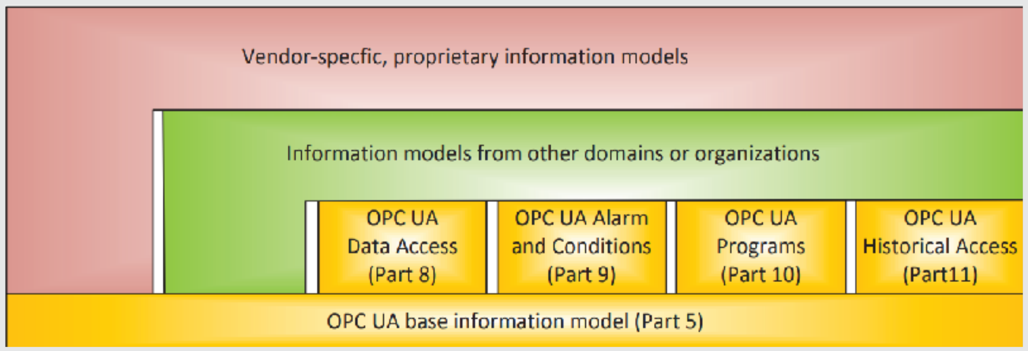


Source: Everyman’s Guide to OPC UA

OPC UA Companion Specifications

The OPC Foundation used their object model design to support legacy OPC DA, OPC HDA, OPC Alarms and Events specifications in the new OPC UA offering. They also support an architecture that allows for custom Information Models to be layered on top of the base offerings. This flexibility supports device manufacturers, machine designers and industry experts with the ability to define semantic models on top of the standard.

FIGURE 23: Industry 4.0 - Digital Twins and OPC UA



Source: OPC-UA

The foundation publishes guidelines and templates for the development of companion specifications. OPC UA Companion specifications are being developed internally by the foundation, jointly with trade associations and externally by private companies. Many of these efforts could provide direct benefit to the US Automotive Industry.

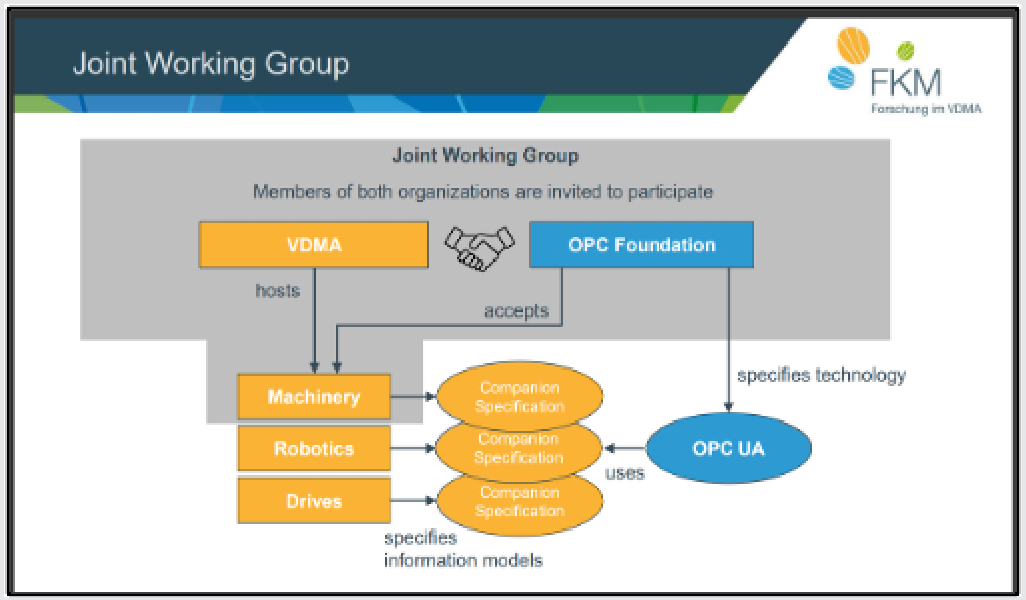
Cross Industry Efforts

The OPC Foundation provides support to other consortiums and standard organizations to develop the OPC UA companion specifications via an infrastructure known as Joint Working Groups (JWG). A Joint Working Group is a working group formed between one or more organizations (subsequently called “cooperating organizations”) and the OPC Foundation. The goal of the JWG is the development of an OPC UA companion standard for use cases defined by the cooperating organizations. If relevant it includes a compliance testing strategy to insure compliant implementations of the OPC UA companion standard. JWGs can help align the efforts of machine suppliers and purchasers alike.

VDMA

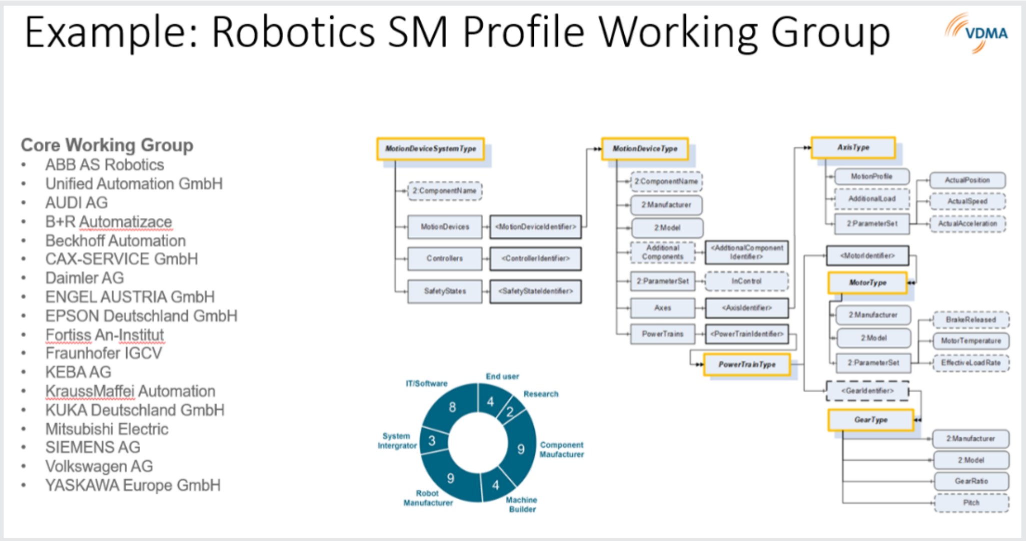
The OPC Foundation is developing many machine companion specifications with VDMA, the Mechanical Engineering Industry Association of Europe. VDMA is the largest network organization and an important voice for the mechanical and plant industry in Germany and throughout Europe. It consists of over 3500 companies and 36 trade unions; its members are collectively the largest industrial employer with 1 million employees in Germany and 4 million employees in Europe. Digitalization and Industry 4.0 is one of the ten key topic areas supported by the consortium. VDMA is developing a Global Production Language in cooperation with the OPC Foundation. This effort is designed to achieve interoperability between a wide variety of machines, components, and systems.

FIGURE 24: Joint Working Group



Source: VDMA

FIGURE 25: Robotics SM Profile Working Group



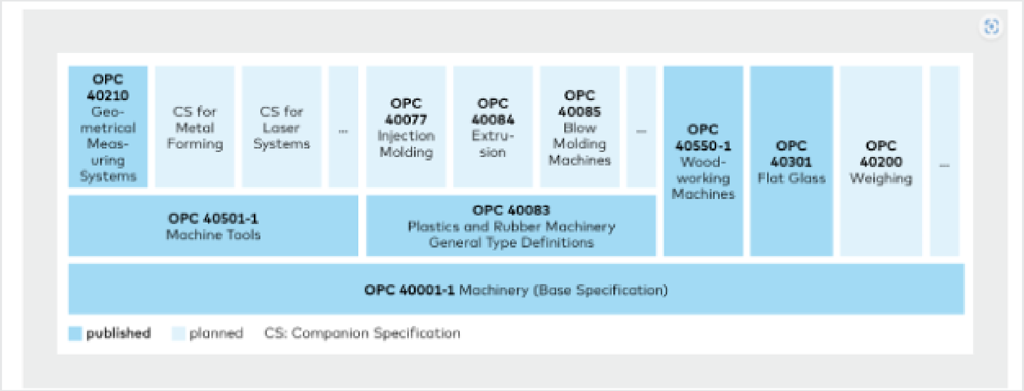
Source: VDMA

Under the auspices of VDMA, experts from around 600 companies are working in more than 35 working groups to develop cross industry machine interface OPC UA Companion Specifications. One of the first specifications they released is the OPC 40001 UA for Machinery. The first release of the specification standardized identification of machines and their components. It supports discovery of all configured machines and components and includes defined machines states that can be used for OEE calculations. This specification has become the cornerstone of a larger community-based standards efforts in Europe supported by UMATI.

UMATI

UMATI is jointly operated by the VDMA and VDW the German Machine Tool Builders Association. Their stated mission is to: “Make connectivity between machinery and software easy, secure and seamless – to help customers exploit added value from data.”

FIGURE 26: Harmonized Interfaces based on OPC UA for Machinery



Source: OPC

UMATI highlights several OPC UA companion specifications in addition to the Base OPC UA Machinery standard. For example, the VDMA OPC Robotics initiative is developing an OPC UA model for motion machines. Over the last few years, the core working group of this initiative, a group of experts from 14 companies, has developed Part 1 of the VDMA OPC Robotics Companion Specification.

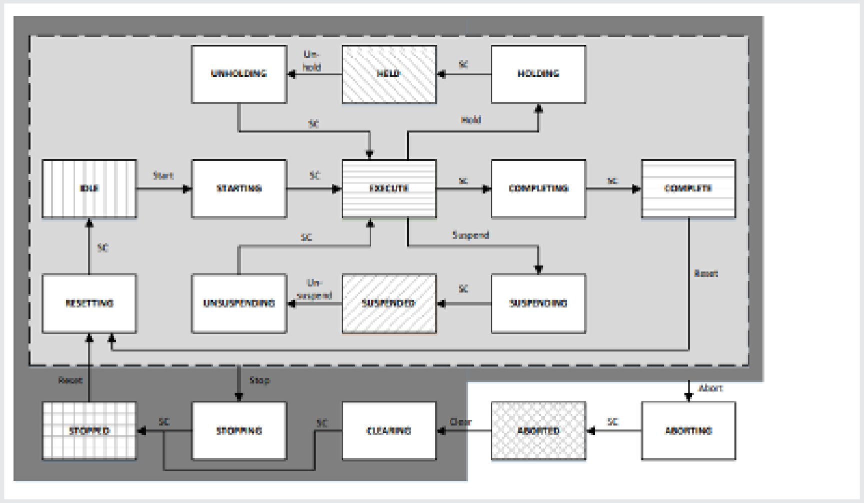
Industry Specific Efforts

OMAC PackML

In 2008, the Organization for Machine Automation and Control (OMAC) and ISA published a standard that makes it easier to transfer and retrieve consistent machine data for packaging and conveying machines. The latest version of this standard was released in 2021.

A PackML-enabled machine offers plant personnel recognizable data from machines that may come from various vendors. That data set includes machine state, operating modes and packets of information that describe a machine’s condition called PackTags. They can contain many kinds of information such as what state a machine is in, time spent in different states, details about recipe changes, speed, rejections and more.

FIGURE 27: PackML Machine States



Source: OMAC & ISA

The OPC UA Companion Specification for PackML was released in 2020 and provides a standardized way to model and communicate data from packaging machinery and equipment using OPC UA and helps to ensure interoperability between different packaging systems. The use of this specification is powerful because it allows packaging machinery and equipment from different manufacturers to communicate and exchange data seamlessly, and it provides a consistent way to access and control the data, thereby enabling integration with other systems such as MES, SCADA, and ERP, improving overall operational efficiency, and reducing downtime and maintenance costs.

The standard is well supported by OMAC. It publishes documents for machine builders that include machine implementation guides and PLC templates for machine state, control modes and PackTag content, OPC UA Server Implementation Guides, OEE Implementation Guides based on PackML tags, and free HMI screens. It also offers companies in the CPG industry RFP Guides for acquiring machines that meet the PackML standard.

ARLA Case Study

Arla is a large food and beverage manufacturing company that works with OEMs on a global scale. They have 70 production sites across the globe in Europe, the U.S. and China. They employ 19,000 people and generate more than 10 billion Euro in revenue annually. A typical packaging line at Arla foods is made up of 7 suppliers located in 4 countries.

In 2016 Arla adopted PackML for machine interfaces and Make2Pack for the automation architecture. The benefits reported by the Arla and the OEMs are remarkable. From the user perspective they saw a 4X reduction in Integration Costs, 5X reduction in Specification Costs and 50% less commissioning time.

The OEM's reported that machines based on the standard are more valuable to the customers, have faster deployment time, include modules that can be re-used across machines, have fewer custom interfaces, need reduced training, and are more easily debugged. All these benefits lead to increased quality and decreased cost.

What started out as a packaging specific effort to ease the work required to integrate packaging machines has evolved into a powerful programming architecture that has numerous advantages that applies to any industry. PackML ensures functional interoperability.

TMC Working Group

The Tobacco Machine Communication (TMC) Working Group was formed to help secondary machine manufacturers design their machines to meet the harmonized requirements of its clients, both in terms of machine-to-machine communication and in terms of machine-to manufacturing system communication. At the time of writing the TMC Working Group consists of the following members:

- British American Tobacco
- Imperial Tobacco Group
- JT International
- Philip Morris International

The TMC working group has released two versions of its OPC UA Companion Specification. The specification builds on the OPC UA core along with the OPC UA Device specification and the OPC UA PackML standards. The data model is designed to support the following use cases associated with production of tobacco and heat-not-burn products.

- Manage machine's Overall Equipment Effectiveness, including identifying downtime and its root causes both for machines and for complex lines where it is important to identify which machine is the root cause.
- Manage production yield, meaning that high-quality machine or line output data is provided altogether with consumption and dispensing information on the input end and material waste and rejections to compute the line mass balance.
- Manage defects, identifying material rejections and their causes, including defect detections and the root cause reasons for detections.
- Enforce MES-integrated production orders for WorkCentres, including the dispatching of recipe datasets and material lists, which are constantly monitored during execution for changes and material integrity.
- Enforce MES-integrated production orders for process cells, including the orderly execution of a production order among WorkCentre units connected in any non -loopy process cell layout.
- Feed a company wide IIoT data stack, including pervasive, structured, high-quality data collection with aggregation directly at the data source for fast changing signals.
- Implement remote control loops, meaning external smart applications, e.g., AI powered, can increase the production quality by controlling remotely existing machines.
- Connect centralized SCADA systems above the machine HMI, including visualization and control functionality in a standardized and uniform way according to the ISA 88 physical structure model.
- Support smart visualization applications above the machine HMI, including visualization resources so that a smart visualization system can programmatically build visualization and control functions.

Koehl Maschinenbau, a Luxemburg-based supplier of processing and logistics equipment for the tobacco industry, has designed an OPC UA server based on the TMC companion specification. This supports the goal of having all machine data follow the same semantic standard.

The application is currently being used on pilot lines to semantically process data in the same way from all machines and analyze it centrally. This is a good example of the marketplace developing products based on open standards.

OASIS and MQTT

OASIS (Organization for the Advancement of Structured Information Standards) is a non-profit consortium that works on the development of open standards for data exchange. One of the standards maintained by the consortium is MQTT (Message Queuing Telemetry Transport).

MQTT is a lightweight, publish-subscribe network protocol designed for communication in machine-to-machine (M2M) and Internet of Things (IoT) contexts. It is designed to be open, simple, and easy to implement.

MQTT is often used in environments where bandwidth and power are limited, such as in remote sensor networks. It was developed by Dr. Andy Stanford-Clark and Arlen Nipper in 1999 to manage oil pipeline equipment that was connected by a low bandwidth satellite network. It is commonly used in industrial automation and control systems, as well as in consumer IoT applications like smart home devices.

MQTT Architecture

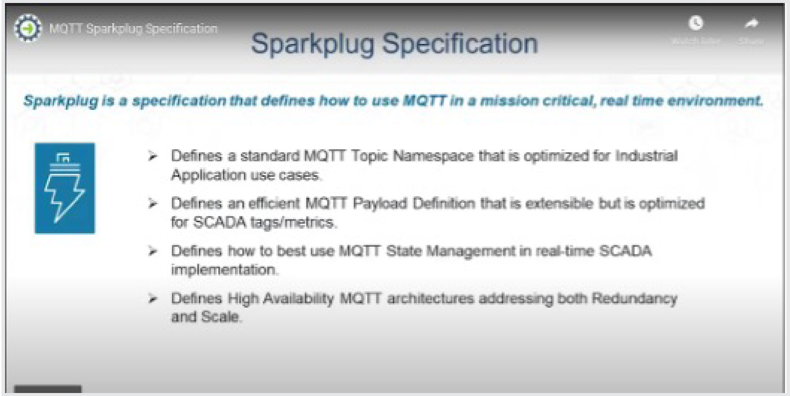
In MQTT, clients send messages to a broker, which then sends them to any clients that have subscribed to the message's topic. This allows for a decoupled communication model, where clients do not need to know about each other and can easily join or leave the network. The protocol also includes features such as Quality of Service (QoS) levels and last will and testament messages, which provide reliability and allow for handling of unexpected disconnections.

MQTT Information Modeling – Sparkplug B

The original MQTT specification does not include a standard for defining information topics or the structure of the data payload. The Eclipse Foundation has developed a specification that specifically supports real-time SCADA (Supervisor Control and Data Acquisition Applications).

Sparkplug B is a specification for MQTT (Message Queue Telemetry Transport) payloads used in IoT (Internet of Things) applications. It defines a standard way for devices to publish data to an MQTT broker, and for other devices and applications to consume that data. The evolution of Sparkplug is governed by the Eclipse Foundation Specification Process (EFSP). Anyone can copy and distribute the specification documents in any medium for any purpose and without fee or royalty.

FIGURE 28: Sparkplug Specification



Source: MQTT

The aim of the Sparkplug Specification is to define an MQTT Topic Namespace, payload, and session state management that can be applied generically to the overall IIoT market sector but specifically meets the requirements of real-time SCADA/Control HMI solutions.

The specification defines a format for the topic and payload of MQTT messages, which includes metadata about the device and the data it is sending. This includes information such as the device's unique identifier, the data type, and a timestamp. This format allows for easy parsing and interpretation of the data by other devices and applications.

FIGURE 29

NAME	DESCRIPTION	EXAMPLE
namespace	Root element that sets the Sparkplug version	spBv1.0
group_id	Logical grouping for MQTT edge nodes	Enterprise
message_type	The message type	NBIRTH, DDATA, others
edge_node_id	Edge node	Site
Device_id	Device Node	Area

Source: MQTT

Sparkplug B also defines a naming convention for topics, which helps to organize and structure the data being published. The naming convention is based on a hierarchical structure, with different levels representing the device, group, and domain. This allows for easy filtering and subscribing to specific data streams.

namespace/group_id/message_type/edge_node_id/[device_id]

The "state management" feature allows devices to communicate their current state and desired state. This allows for easy control and monitoring of devices and the ability to detect and resolve issues.

Finally Sparkplug B supports "birth and death" messages. Birth messages are sent by a device when it first connects to the broker, and death messages are sent when the device disconnects. These messages help to manage the lifecycle of devices and ensure that the system is aware of which devices are online and available.

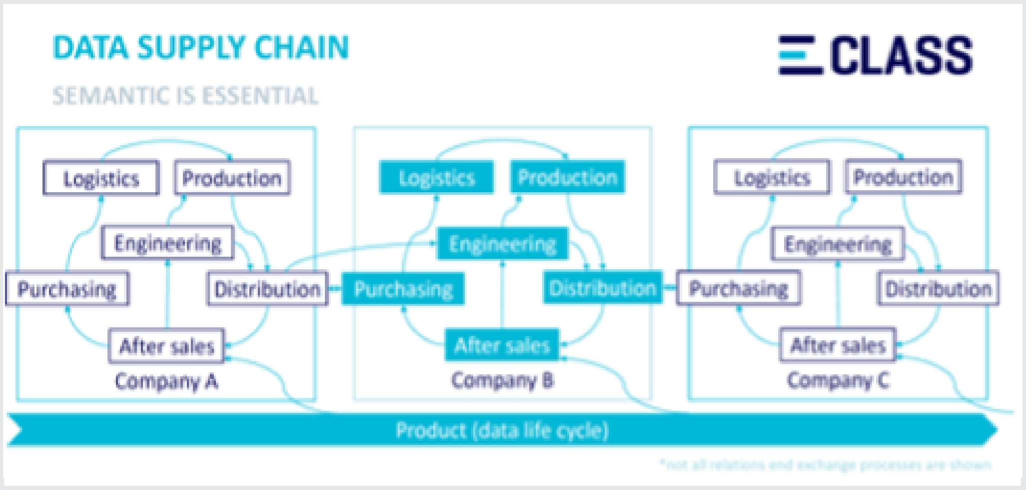
MQTT Unified Namespaces

The term "unified namespace" was coined by Walker Reynolds of 4.0 solutions. It refers to an event driven architecture that allows for communication between nodes in a network.

It typically utilizes MQTT or Apache Kafka as a central message broker that is easily scalable. This contrasts with the traditional automation pyramid common with Industry 3.0 implementations and would support messages from both IT and OT systems and promote access to a normalized data set for an enterprise.

E-Class – PLM Data Standards

FIGURE 30: E-Class | PLC Data Standards



Source: E-Class

ECLASS is the global reference data standard for the classification and unambiguous description of products and services. Why ECLASS? Because a standardized master-data system is essential to enterprise-wide improvements. Because ECLASS sets the semantic standard that makes Smart Manufacturing possible and the Internet of Things a reality. And because ECLASS, as an open standard, is constantly evolving and can be adapted to individual user needs. More than 4,000 companies are already taking advantage of these benefits. Increasingly, they are also specifying ECLASS as a mandatory standard for their business partners.

The ECLASS organization was founded by 12 German companies (Including Siemens, BASF, AUDI/VW, SAP, Bayer, and others). The organization aims to simplify the electronic, cross-industry trade through standardized product descriptions. ECLASS has established itself internationally over 18 years as the only ISO/IEC-compliant industry standard and is thus the worldwide reference-data standard for the classification and unambiguous description of products and services.

The current version 10.1 spans across 44 segments, over 42,000 product classes and 18,000 uniquely described properties. We believe ECLASS has a strong presence in EU and is fast spreading in China, Japan, and North America as a master standard where product master data can be exchanged digitally across all borders – across sectors, countries, languages, and organizations. As a simple, machine-readable, one-to-one, ISO-compliant, and yet open system, the standard is growing faster than all others. Because it is defined by its users, it is vital and based on real-world practices. In sum, ECLASS is built on the world's expert knowledge. Currently, ECLASS is used in about 3,500 companies both nationally and internationally.

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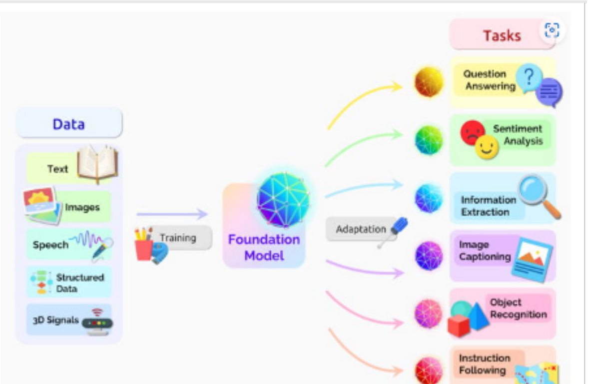
Foundation Models

Automotive manufacturers have been involved in high-performance computing since the 1980's. Efforts have progressed from expert systems through machine learning and task-specific deep learning over the past four decades. However, foundation models and generative AI have the potential to generate trillions of dollars of economic value and will change the monolithic view of application architectures.

Foundation models are AI neural networks trained on massive unlabeled datasets to handle a wide variety of jobs from translating text to analyzing images. They learn on massive amounts of unlabeled data but can be fine-tuned when supplemented with labeled data. They were first described in a 2021 paper released by a team of more than a hundred Stanford researchers.

FIGURE 31: Foundation Models



Source: NVIDIA: What is a Transformer Model

Example foundation models available to the public include the language model ChatGPT and image generation model Dall-E 2 from Open AI and the AI paired programming tool GitHub Copilot.

Example Use Cases

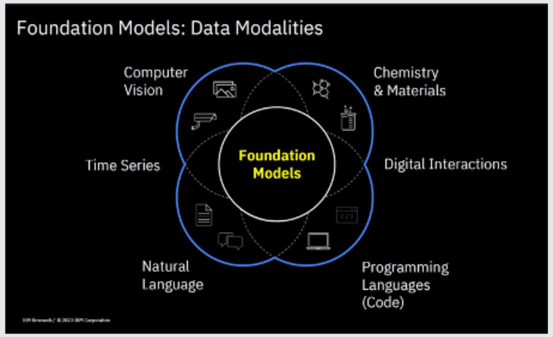
IBM research reports that early non-optimized Foundation Models exist for Industry 4.0 verticals; and that they are more accurate than models based on Long Short-Term Memory (LSTM) neural networks or state-of-the-art regression models.

IBM Research discussed foundation models at a recent meeting of the National Academies of Sciences, Engineering and Medicine. The meeting was one of three held to review the Options for a National Smart Manufacturing Plan.

The first use case leveraged a code-based model to transform a 10-year-old warranty application for a major automotive manufacturer. The AI model used runtime traces, use cases and metadata to recommend and auto-generate custom microservices for the replacement application architecture. It is estimated that the approach reduced the completion time by a factor of 12.

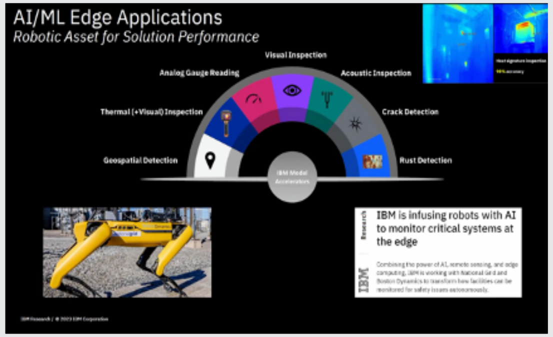
The second use case reviewed involved robotic inspection and edge analytics are being combined to monitor the health of the national grid.

FIGURE 32: Foundation Models: Data Modalities



Source: IBM Research

FIGURE 33: AI/ML Edge Applications



Source: IBM Research

APPENDIX B

Workforce development

Building a Skilled Smart Manufacturing Workforce

Dr. Sudarsan Rachuri of the U.S. Department of Energy recently kicked off a workshop on Education, Training and Workforce Needs for Smart Manufacturing. In that meeting he addressed the public sentiment that U.S. manufacturing jobs are “Dirty, Dangerous, and Disappearing.” He also noted that while 70% of Americans want a return to manufacturing only 30% advise their children to pursue manufacturing as a career. He further noted that an estimated 2.1 million manufacturing jobs will be unfulfilled by 2030.

Industrial Workforce Challenges

Dr. Laine Mears from the Clemson University International Center for Automotive Research reported on the results of an Industrial Challenges Study that was conducted with focus groups from 20 companies, Automotive OEMs, and suppliers in 2022.

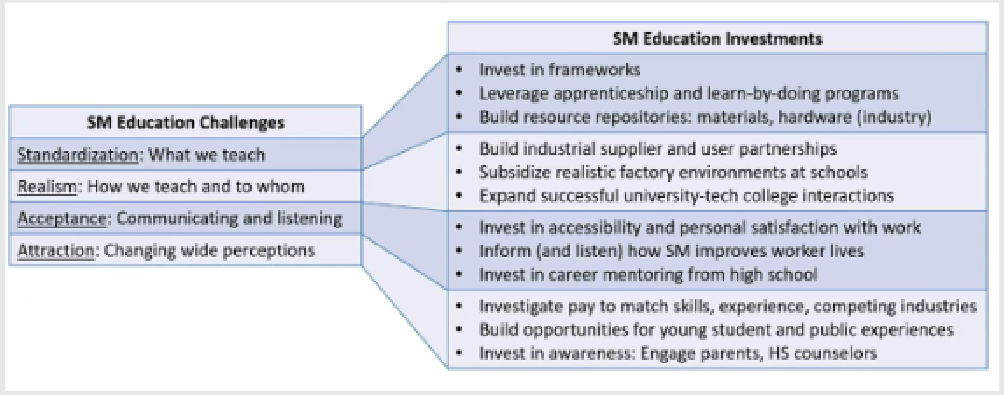
FIGURE 34

Hiring	• Finding enough candidates (availability or perception issue?) • Finding qualified candidates (experience, preparation, interest) and paying them • Attrition – Manufacturing is challenging work!
Work Variability / Training	• Inattention, lack of engagement to process • Lack of effective mentoring to reinforce training (start during education?) • Differences in training style and depth, lack of formality • Subjectivity of some tools
Incorporating the Worker	• Not always possible or cost effective (e.g., Assembly) • Lack of automated feedback to worker (e.g., display only, latency, single-loop) • Lack of prescriptive understanding (what tech is available, best way to implement it) • Tech is easily discarded, easy to revert to the old way at each hiccup
Technology acceptance	• Worker unfamiliarity (one can’t see the benefit) • Discomfort (noted by worker, not R&D) • Centralized dictation of technology (no local control)

Source: Industrial Challenges Study

Dr. Mears outlined four Smart Manufacturing Education Challenges and the corresponding Investments that must be made to address them.

FIGURE 35

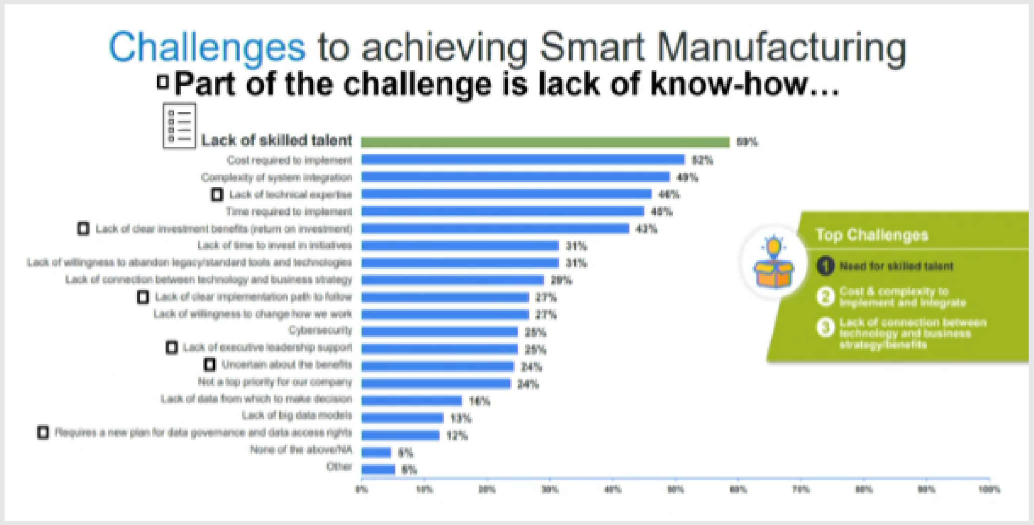


Source: Industrial Challenges Study

CESMII Education Projects

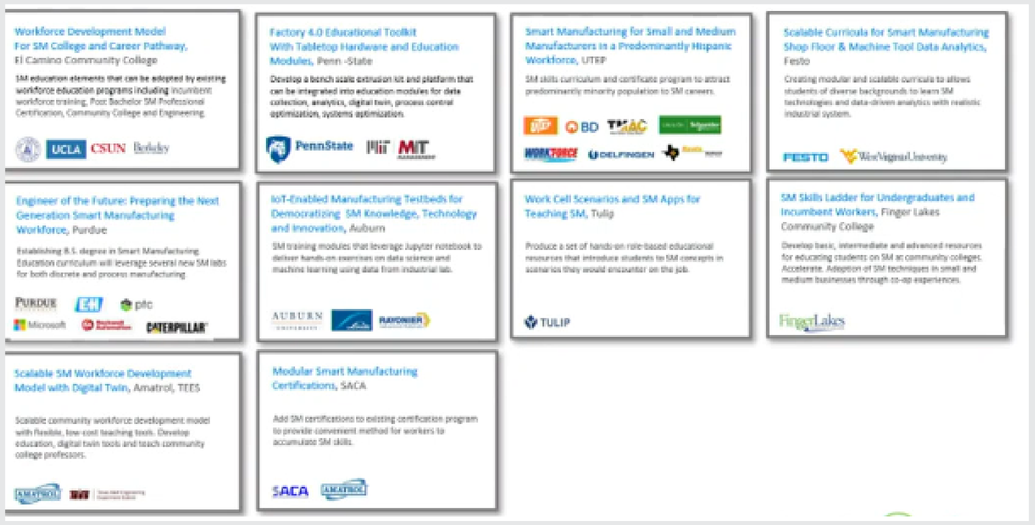
One of CESMIIs missions is to support the nation's manufacturing learning infrastructure through development of extensive and innovative Smart Manufacturing educational resources. From educating manufacturing leaders and professionals to upskilling the workforce, we are fostering adoption of broad-scale SM initiatives throughout the U.S. CESMII funds numerous projects in direct support of training a SM Workforce.

FIGURE 36



Source: CESMII - The Smart Manufacturing Institute

FIGURE 37

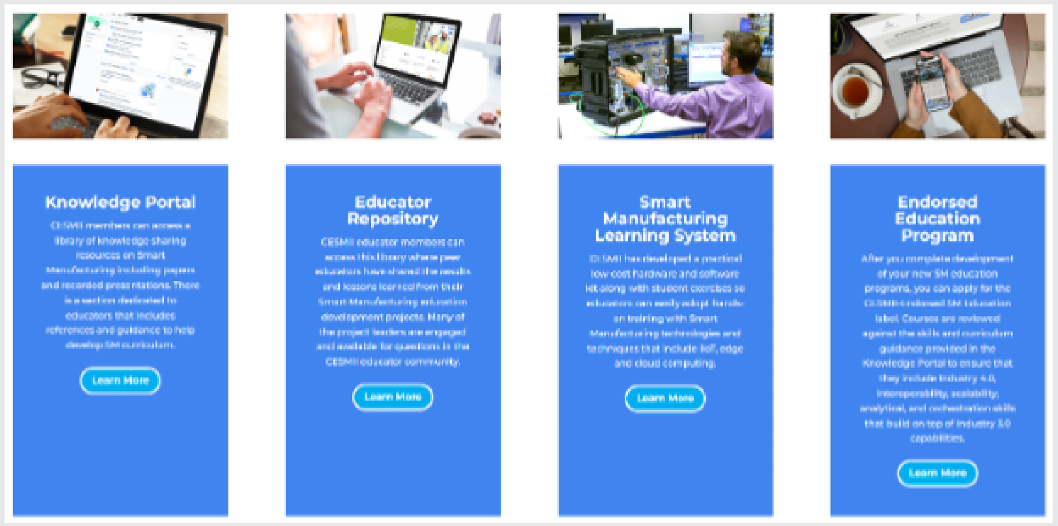


Source: CESMII - The Smart Manufacturing Institute

CESMII Educator Resources

CESMII hosts a collection of information for professors and trainers teaching SM principles, skills and ideologies at universities, community colleges, training centers and in the workplace.

FIGURE 38: CESMII Knowledge Portal



Source: CESMII - The Smart Manufacturing Institute

The CESMII Member Knowledge Portal provides an online catalog of Smart Manufacturing (SM) knowledge resources for member organizations. It is an opportunity to learn about Smart Manufacturing in a self-paced way. Whether you are looking for papers or videos on introductory or more advanced topics, the Knowledge Portal is the place to get started with your journey.

Some topics covered on the portal include:

- What is Smart Manufacturing?
- What are the foundational building blocks of Smart Manufacturing?
- How do we make sure we have a good technology-enabled business strategy?
- What are the benefits companies are realizing with Smart Manufacturing techniques?
- How to leverage Machine Learning in Manufacturing?
- How do we save energy and create a more sustainable manufacturing process?
- How do we augment our workforce capabilities with Smart Manufacturing capabilities?
- What does Smart Manufacturing curriculum look like? What are the fundamental topics?
- How do we integrate the multiple layers of systems connecting sensors, machines, databases, analytics, and enterprise systems?
- How do you create information models in the SM Innovation Platform?
- How to leverage the library of information models available through industry groups to help align your internal integration efforts with your industry partners?
- **And many more topics...**

CESMII Tooling U | SME

A significant collaboration in the Tooling U-SME and CESMII workforce partnership is the Fundamentals of Smart Manufacturing learning package that covers essential methodologies for today's manufacturing ecosystem. SM impacts many job roles, from leadership, engineering, and the frontline workforce to educators training the next generation of manufacturers. These new resources set a common foundation and language that enables cross-disciplinary innovation, ensuring American manufacturing competitiveness.

Tooling U-SME works with thousands of companies, including more than half of all Fortune 500® manufacturers and nearly 1,000 educational institutions across the country. Tooling U-SME focuses on the design and distribution of learning resources, and tailoring solutions to the needs of the manufacturing community. With Tooling U-SME's extensive training experience, its reach into industry and academia, and CESMII's subject matter expertise and expertise in Smart Manufacturing technology and business practices, the CESMII and Tooling U-SME collaboration will expedite adoption and drive progress through transformational workforce development.

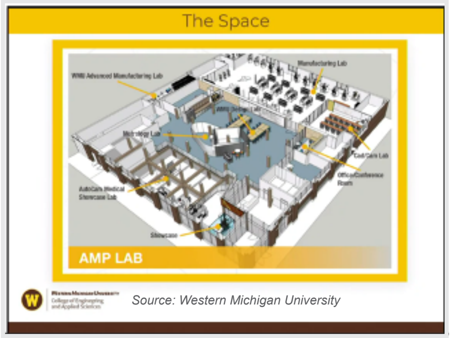
Course Offerings include:

- Introduction to Smart Manufacturing
- Capturing and Organizing Data
- Connecting Data, Platforms and Systems in Smart Manufacturing
- Providing Insights for Enhanced Decision Making
- Automating Flow and Control
- Cybersecurity

Educational Support in the Great Lakes Region

The Great Lakes region is rich with educational support for Smart Manufacturing. Western Michigan University, Lorain County Community College and Purdue University are just a few of the institutions working to support the training needs of Smart Manufacturing in the U.S.

FIGURE 39



Source: Western Michigan University

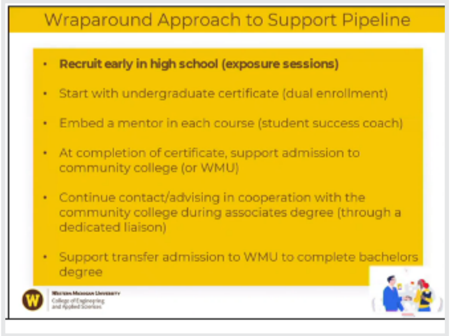
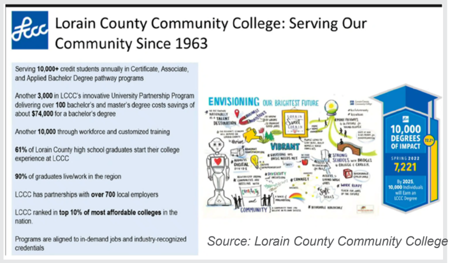


FIGURE 40



Source: Lorain County Community College

FIGURE 41

Source: Purdue

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