PROGRAM PLAN

Program Title: Model-Based Enterprise

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ABSTRACT:

The Model-Based Enterprise (MBE) program aims to answer how a manufacturer can match product needs to process capabilities to determine the best assets and ways to produce products to support U.S. industry's competitiveness and address industry's need for interoperability across decentralized systems. Replacing a manufacturing system completely is costly. Thus, manufacturers need the ability to manage the development, re-development, and deployment of new sub-systems in the immediate presence of existing (legacy) applications and systems. The MBE program will address the industrial need by researching the coupling of existing technologies with integrations of system, service, product, process, and logistics models, to enable advanced variant configuration -- allowing Industry to be agile and flexible enough to manufacture closer to the end user, in varying lot sizes, with better first-time yields.

OBJECTIVE:

The Model-Based Enterprise (MBE) Program will develop and deploy advances in standards, test methods, and measurement science that enable manufacturers to integrate system, service, product, process, and logistics models across the manufacturing enterprise.

WHAT IS THE PROBLEM?

The National Security Strategy says producing needed parts and systems, healthy and secure supply chains, and a skilled U.S. workforce is essential for ensuring the Nation's manufacturing readiness and economic and national security [1]. In executing a Digital Engineering Strategy, the United States Department of Defense believes a successful digital transformation of manufacturing using digital and model-based engineering practices will address enduring challenges associated with complexity, uncertainty, and rapid change in deploying and using systems [2]. Support for a vibrant domestic manufacturing sector, a solid defense industrial base, and resilient supply chains is a national priority [1].

A 2016 Deloitte report recommends that individual manufacturers should also recognize making sourcing or location decisions largely based on cost alone is not a sustainable strategy [3] McKinsey found making decisions on how and where best to deploy digital, automated, and analytic technologies is difficult in today's manufacturing environment due to organizations' legacy states and the existing interconnections between customer-facing and internal processes [4]. Further, in a 2016 Deloitte survey, global CEOs ranked predictive analytics, smart and connected products (IoT), smart factories (IIoT), and digital design / simulation / integration as part of their top five most important advanced-manufacturing technologies [3]. McKinsey identified that a systematic analysis is necessary to guide executives through considering various sequencing scenarios, evaluating the implications of each, and making decisions to benefit the entire business [4].

Manufacturers have been chasing, for decades, the ability to make efficient and effective decisions on how best to plan product routings and manage inventory forecasting. Manufacturers use the formula where profits are equal to the selling price of their services minus the cost of operating those services. Small and Medium Enterprises (SMEs) are more sensitive to that formula because they have less flexibility in absorbing under-performing profit estimates. Manufacturers want the ability to answer questions in near-real-time such as: 1) how do I make my inventory management more efficient or 2) how do I match the supply of product that I'm making with the actual demand?

Decentralization of manufacturing systems has amplified the problem of collecting and communicating the product and process specifications needed to make decisions about product development, production, and supply chains tasks while delivering products to market. For example, with the growth of global production networks, original equipment manufacturers (OEMs) have increasingly become system integrators rather than just manufacturers. Further, the difficulty of gathering actionable intelligence and lessons learned from processes later in the lifecycle to ensure better decision making earlier in the lifecycle is also amplified.

Gathering the information needed to support decision making from a specific perspective is difficult. Required data is stored across several enterprise systems under various functional control (e.g., design, manufacturing, quality, maintenance). Harvesting needed data manually from disconnected systems scattered across a global enterprise requires significant human capital. Industry continues to pursue more agility, flexibility, and productivity in its product development and manufacturing operations, which requires customer involvement in the product development process, enables more individualized products, and improves the overall effectiveness and efficiency of existing manufacturing systems. Ensuring data is available in the right domain, at the right time, and in the right context is more important than ever.

Furthermore, both small and large manufacturers have identified opportunities to leverage external capacity to provide flexibility. For example, SMEs often have excess capacity that can be monetized by providing services to OEMs needing resources to meet planned or unplanned production changes. But, matching needs to excess capacity is too costly in a paper-based enterprise. These trends have contributed to a growing interest in distributed and federated manufacturing systems composed of heterogeneous components having a means of semantic interoperability that enables the coordination and control of activities.

Companies are also expanding beyond their traditional service offerings. For example, shipping firms [5] are re-branding as logistics management firms. Further, these firms are developing and deploying IIoT technologies to monitor package flow and routing management [6]. Alan Amling, vice-president of strategy at UPS, speaks [7] to manufacturing and technologies like IIoT as, “really an ecosystem of technologies that work together. It's not just one thing, it's many things that are working together.”

However, taking advantage of the growing trends is not possible in today's heavily paper-based process of moving information across the lifecycle. Industry requires both vertical integrations within domains and horizontal integrations between domains to ensure “information silos” are no longer barriers to effective and efficient decision making. Horizontal integration requires connecting heterogeneous information and systems, which implies the need for semantic mediation. Unfortunately, today’s information models (or behaviors, methods, interfaces, messages, services) are not completely described with sufficient precision to enable translation of data (e.g., syntactic integration) and/or semantic interoperability.

Each phase of the product lifecycle has different viewpoints and concerns, which lead to different levels of abstraction in modeling and simulation. The various viewpoints lead to information models, services, and systems being developed for a specific purpose, which results in different information models across phases of the lifecycle to look at the same data in different ways. A “fit for purpose” approach to modeling is typically recommended because it enables “expert systems” that support the user (i.e., human), in a specific function and role, to make decisions in a contextual way.

Conversely, purpose-built models are not scalable and often “siloed” into a single domain. Purpose-built, single-focus models in different domains offer too limited a scope for making the best decisions for the enterprise. While a domain-specific model may seem optimal for making decisions related to that domain, considering only the domain’s viewpoint is likely to result in non-optimal results for other parts of the enterprise. Additionally, data requires context when related to decisions. Data alone is not sufficient for decision making because the decision maker must understand the scope and type of the problem the decision is intended to solve. As the scope of the problem changes, the models must also change. Thus, connecting heterogeneous information and systems to enable product-to-process matching in manufacturing introduces a paradox to the steadfast approach of purpose-driven modeling. A trade-off of how to make a model purpose-built versus how to make a model scalable must be considered with the shift towards better product-to-process matching.

The global economy moves faster than ever and continues to speed up. While there is uncertainty in predicting if the economy will slow down or speed up, there is a clear indication that manufacturers are struggling to keep pace. John McNiff, Vice President of Solution Management at SAP, said [8], “What’s changing now is the speed required to deliver a lot size of one. Consumers are no longer willing to wait 15, six, or even three months. Innovation is moving from mechanical features to embedded software, driving a need to condense design cycles -- and a convergence of silos. Non-integrated, non-real-time solutions won't support the next wave.” Addressing the challenge McNiff highlights requires integrating domains in multiple directions while providing scalable contextual models. Industry also requires an effective and efficient forward and backward communication backbone. Overcoming these challenges is not easy, but a standards-based approach, using the digital thread built on open architectures, provides the best opportunity for maximizing the successful deployment of technology and realizing of benefits in distributed environments.

Open standards-based technology is lacking the ability to enable manufacturing systems to communicate, interact, exchange information, make decisions, detect and respond to faults, and perform in a collaborative and reliable manner. Specific needs include standard data models for products and process, messaging and integration standards, and methods for visualization, dynamic control, and knowledge generation in manufacturing operations. The U.S. DoD expects the benefits of digital engineering to include better informed decision making, enhanced communication, increased understanding and confidence in system design, and a more efficient engineering process [2]. Further, filling technology gaps identified by the MBE program will enable widespread adoption of model-based enterprise and increase America’s opportunity to obtain a greater manufacturing market share in the global environment. NIST participation is needed to speed development in the digital transformation of manufacturing.

WHAT IS THE NEW TECHNICAL IDEA?

The American Society of Mechanical Engineers (ASME) [9] and others advocate that democratizing emerging technologies into SMEs will ensure the U.S. industrial base remains competitive. To support U.S. industry’s competitiveness and address industry’s need for interoperability across decentralized systems, the MBE program aims to answer how a manufacturer can match product needs to process capabilities to determine the best assets and ways to produce products. Successfully addressing the aim would ensure distributed decision making with a system focus such that applying control across the product lifecycle is based on predicted and expected outcomes -- thus, enabling requirements-based operations. The program will make scientific and technical contributions to standards and test methods by delivering guidelines, recommended practices, and reference open architectures for requirements-based operations across the product lifecycle.

The new technical idea is to provide tools and guidance to industry for making decisions in distributed environments with a system focus using operational control methods to ensure outcomes are based on requirements. While the problem described previously is large, the MBE program will address a sub-set of the problem by scoping research to the use case of matching product-specification requirements to process-capability, including managing capacity and availability of the processes to enable dynamic scheduling. Both distributed and federated systems can be integrated using the digital thread to form a model-based enterprise. MBE supports linking each portion of the lifecycle and requires a means to integrate information and the structure of that information. The growing body of work from artificial intelligence (AI), industrial internet of things (IIoT), and cyber-physical systems (CPS) can support the continued development of MBE. Those bodies of work, in synergy with the other NIST smart manufacturing programs, will be leveraged to link the various phases, viewpoints, and systems of the product lifecycle, which will allow OEMs and manufacturers to make better decisions in delivering higher-quality products to market in distributed ways that are faster, cheaper, and more sustainable.

The new idea addresses the standards, test methods, and measurement science needs in smart manufacturing in the following ways:

- Develop and standardize methods and protocols that facilitate analysis of products, processes, and logistics, by unifying domain-specific analysis information and integrating it with systems modeling information
- Develop and transfer to industry advances in standards and measurement science for model-based messaging standards and service-modeling methodology to enable manufacturers to improve the agility of manufacturing systems
- Develop and deploy advances in standards, conformance testing, user-awareness, and adoption of 3D model-based product definition standards to improve product quality and reduce costs for manufacturers throughout the product lifecycle
- Develop and deploy advances in methods, standards, and software tools for data visualization and exploration for improving the efficiency and agility of smart manufacturing systems
- Develop and deploy advances in standards and measurement science to enable manufacturers to define, measure, and control the capability of smart manufacturing systems
- Develop and deploy advances in standards and test methods for operations and logistics that improve the reliability, quality, and efficiency of smart manufacturing systems
- Develop and deploy advances in standards, measurement science, and software tools using actionable, computable, domain knowledge stemming from informal natural language manufacturing data to augment a manufacturers' ability to perform model-based and data-driven analyses

WHAT IS THE RESEARCH PLAN?

The research plan consists of a portfolio of interrelated projects that focus on key areas of the standards, test methods, and measurement science needed to achieve successful development and implementation of model-based enterprise principles. Collectively the projects provide a comprehensive approach that will lead to new industry standards and practices, which will result in efficient dynamic manufacturing systems. Where appropriate, assessment efforts will be initiated to further elicit and analyze industrial requirements. These requirements will assist in scoping the projects and guiding the development and standardization work in subsequent years.

The MBE program will also assume responsibility for the planning and execution of the MBE Summit during the month of April each year of the program. The MBE Summit will be an anchor event of the program to support the dissemination of information, technical transfer, and adoption in MBE. Each project from the program will support the recruitment of high-quality publications and presentations, while also working to grow the MBE community of interest.

The use case of matching product-specification requirements to process-capability capacity and availability is a high priority of industry and will be used as the research theme that integrates the projects into a cohesive program. The program will address standards, test methods, and measurement science for product definitions and manufacturing capability definition to successfully address the research aim discussed earlier. Then, the program will work to recommend methods for matching, aligning, and analyzing product and capability definitions for making the best possible decisions in product development, manufacturing, and supply-chain planning. The program has seven projects focused on four areas: 1) enterprise integration, 2) product definition, 3) capability definition, and 4) operations and logistics. The MBE program structure is as follows:

- Enterprise Integration focused projects
    - Model-Based Systems Definition and Analysis Integration for Smart Manufacturing
    - Model-Based Manufacturing Services
- Product Definition focused projects
    - Product Definitions for Smart Manufacturing
    - Product Lifecycle Data Exploration and Visualization
- Manufacturing Capability Definition focused projects
    - Model-Based Manufacturing Capability Definition
- Operations and Logistics focused projects
    - Model-based Smart Manufacturing Operations Management
    - Knowledge Extraction and Application for Manufacturing Operations

The Model-Based Systems Definition and Analysis Integration for Smart Manufacturing Project will develop methods and protocols to enable efficient integration of smart manufacturing systems models and analysis models, by unifying discipline-specific analysis information and integrating it with existing systems modeling information. Smart manufacturing system development and operations are difficult to manage because information about the systems and their analysis is expressed in redundant and incompatible ways across the multiple engineering disciplines involved (e.g., electrical, materials, process). Integrating information about overall system requirements and structure with discipline-specific information is costly because analysis models use concepts and formats that are partially redundant and inconsistent with each other, and with overall systems models. Manufacturers and solution providers will be able to operate smart manufacturing systems faster and cheaper, by analyzing systems more efficiently. NIST has extensive and unique experience in enabling efficient exchange and use of systems and engineering information between tools. It is best positioned as a neutral party to make this available to manufacturers and solution providers developing and operating smart manufacturing systems.

The Model-Based Manufacturing Services project will develop measurement science, methods, and tools to reduce the costs and risks to manufacturers in making the transformation towards a service-oriented manufacturing system (SOMS). A SOMS is a dynamic composition of networked manufacturing software and cyber-physical components offered as services. Leveraging benefits from new smart manufacturing technologies (e.g., IIoT, AI, Big Data Analytics) requires manufacturing systems to transform towards a service-oriented architecture. Transformation to SOMS is necessary if manufacturing systems are to respond effectively to dynamic market demands and disruptions. Although manufacturers can see the benefits the new architecture may bring, they face several difficulties in making the transformation.

The Product Definitions for Smart Manufacturing project will deliver methods, protocols, and tools for developing, conformance testing, increasing user-awareness, and industrial adoption of product definition standards necessary for the digital transformation of manufacturing enterprises.

Smart manufacturing research at NIST has promoted a vision of fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs. This vision is increasingly achievable by small-to-medium sized enterprises due to development of increasingly capable standards for conveying industrial data. NIST has had success in developing and promulgating product definition standards for manufacturing, however, there is still a great need for NIST leadership and research to continue those efforts.

The goal of the Product Lifecycle Data Exploration and Visualization project is to develop and deploy advances in methods, standards, and software tools for data visualization and exploration for improving the efficiency and agility of smart manufacturing systems. The project will focus on developing, curating and disseminating reproducible, reference implementations of manufacturing data pipelines for improving the efficiency and agility of manufacturing operations. With the continuing emergence of low-cost, lightweight, and powerful hardware at the edge, opportunities grow for advancing methods, standards, and software tools for data exploration and visualization for smart manufacturing systems. Small and medium-sized enterprises have limited resources to effectively implement standard and reproducible analyses of their manufacturing operations to draw timely and actionable insight. Without formal standards, tacit knowledge embedded in the most experienced employees is not easily transferrable to novices. Given the recent advancements in computing efficiency (hardware) and intuitive visual interfaces (software), techniques for interactive data exploration can help close this gap. According to a 2016 McKinsey Report, the demand for visualization increased about 50% annually from 2010 to 2015. As the field of interactive visual exploration continues to grow, there will be deeper needs for standards to facilitate faster adoption.

The Model-Based Manufacturing Capability Definition project provides technical contributions to define, measure, and control these manufacturing capabilities. MBE requires information about the capability (i.e., provided value) of a manufacturing system to enable systems-focused decision making such that outcomes (i.e., requirements) drive control across the product lifecycle. The challenge of this work is that manufacturing capabilities are inherently dynamic and vary based on the type of manufacturing system to control and the type of decision to be made. The research in this project focuses on the manufacturing capability of a flexible, on-demand, pull-production work cell composed of a machine tool, coordinate measurement machine (CMM), robot, buffer, and material conveyance. Success in this research would improve the agility, flexibility, and competitiveness of the US manufacturing base by allowing decisions to be made based on the measured and predicted capability of manufacturing systems as well as additional part and process information.

The Model-based Smart Manufacturing Operations Management project will contribute to standards and test methods that normalize models and methods for specifying and connecting shop floor information to operations decision making and execution. This project will improve the utilization of available information by synthesizing and contextualizing information from traditionally incompatible sources (“linking” data together). This information is used by operations management systems to optimize system efficiency through operational control, reliability, and logistics. The result is increased manufacturing system efficiency through improved operations management capabilities leveraging linked data.

Lastly, Knowledge Extraction and Application for Manufacturing Operations proposes a hybridized AI and expert-driven framework for quantifying human knowledge, in which Natural Language Processing and graph-theoretic methods are introduced, to assist in “tagging” and analyzing unstructured information to enable decision making and continuous improvement. This project will contribute to domain-specific standards and associated open source toolkits for extracting knowledge to improve manufacturing decision making. The project will first focus on manufacturing maintenance work orders for FY19 and then will expand to analyzing other manufacturing natural language documents in future years.

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