Web-enabled and Tether-Free Augmented Modeling and Simulation Technologies for Next-Generation Product Design, Manufacturing, and Service

Jay Lee
Wisconsin Distinguished and Rockwell Automation Professor
University of Wisconsin-Milwaukee, USA &
Professor and Co-Director of Industrial innovation Center (IIC)
Shanghai Jiao Tong Univ., China
jaylee@uwm.edu

Abstract

This paper addresses the innovation needs in using web-enabled and tether-free technologies to augment modeling and simulation for next-generation product design, manufacturing, and services. First, an introduction on fundamental needs on "5Ps (*predictability, producibility, productivity, pollution prevention, and performance)"* in modeling and simulation is given. In addition, perspectives in using e-manufacturing for next-generation materials processing and product manufacturing design are discussed. Finally, an effort in establishing a networked research centers in for next-generation product design, manufacturing, and service is discussed. An example on One-Day-Design Studio established at the Industrial Innovation Center of Shanghai Jiao Tong Univ is introduced.

Keywords: modeling and simulation, innovation, e-manufacturing

1. Introduction

For the past five years, the impact on web-based e-system technologies has added "*velocity*' into our product design, manufacturing, and business operations. Business automation is forcing companies to shift operations from the traditional "*factory integration*" philosophy to a "*virtual factory*" supply chain management philosophy. The technological advances for achieving this highly collaborative design and manufacturing environment is based on multi-media type information-based engineering tools and a highly reliable communications system for enabling distributed procedures in concurrent engineering design, remote operation of manufacturing processes, and operation of distributed production systems. This transition is dependent upon the advancement of next-generation manufacturing practices on "*e-factory and e-automation* " which is focused on the use of information to make things happen collaboratively on a global basis. Increased use of modeling and simulation presents a major opportunity for improving the capability of the engineering enterprise to provide competitive differentiation for our products. From a broad perspective, modeling and simulation refers to a methodology for describing an understanding of how and why a product or process operates the way it does. Successful application of modeling and analysis, simulation, and computation implies (at the least) the ability to reliably predict, in a timely manner, the performance of a system or the effectiveness of a process, and thus to evaluate the effect of proposed engineering changes in components and approaches to development. For many products, modeling and simulation is a methodology that provides critical insight into the fundamental phenomena that define the limits of their performance. By understanding these barriers, we can reliably design our systems to achieve the best combination of performance, range of operating conditions, quality, and price. For our processes, modeling and analysis is a way to ensure that our capabilities are well matched to our product goals and that the resources spent in product development produce maximum results.

Accumulated data and experience are used as the sole guide to new products, leading to systems that may be far away from the fundamental limits of performance and cost, and processes that are longer (and thus more costly) than necessary. In these situations, exploration of new regimes of operation can only be accomplished

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with extensive building and testing of prototypes, which is both expensive and time consuming. Further, the lack of knowledge of the physical phenomena that characterize the system behavior makes us vulnerable to unanticipated problems that invariably occur late in the design process or out in the field. In short, the current approach does not provide a framework or context with which to understand problem development, validation, or failures from a first-principles perspective.

This white paper gives a vision for the use of web-enabled an tether-free technologies to augment modeling and simulation for next-generation product, manufacturing, and service.

2. **Research Issues and Needs for Next-Generation Product Design, Manufacturing, and service**

Future smart manufacturing companies necessitate a set of core intelligence to address the issues of smart business performance within the integrated design, manufacturing, and service business system. This set of core intelligence is called *"5Ps*," namely *predictability, producibility, productivity, pollution prevention, and performance* (Figure 1).

The study of these characteristics has made the integrated design, manufacturing, and service a challenging system discipline. The author believes that we must understand these issues as a scientific discipline and seamlessly integrate them into the design and manufacturing enterprise. When we understand this integrated engineering system as a science, we can subject it to well-established analysis methods. We can then determine what the basic parameters are and how they should be measured, thus predicting expected behavior. When we can measure, we can control; and when we can control, the process can be continually improved. Most important, this discipline must be understood by everyone involved in the product design and manufacturing processes. With such a scientific understanding of the subject, we can analyze the effects of behavioral changes and select the optimum course of action during the life cycle of the product.

Modeling and simulation needs to effectively address these needs. A general principle is that the best model for a given circumstance is not necessarily the description with the highest level of fidelity. There is a balance between the problem being addressed, the amount of time available to obtain a solution, and the type and

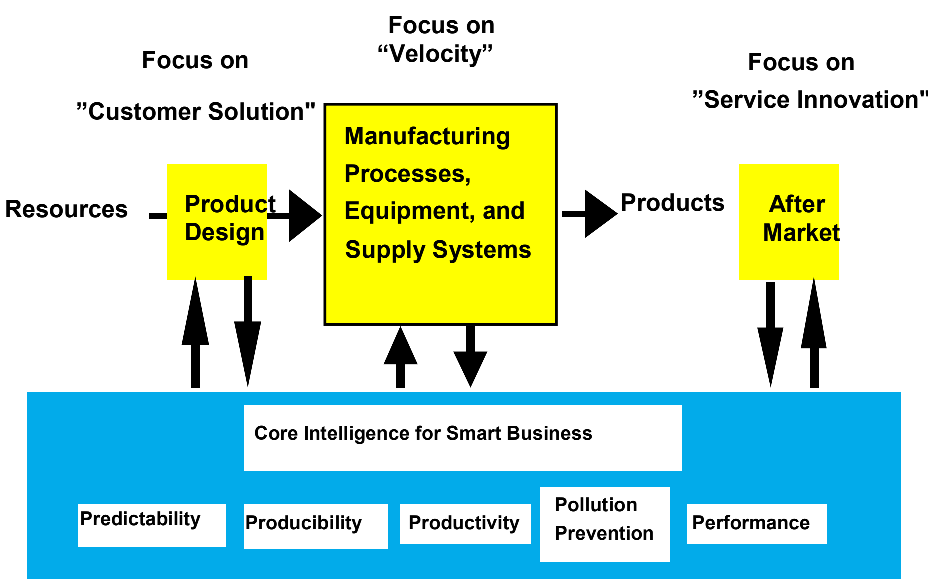

Figure 1. *"5Ps" for Next-Generation Product Manufacturing*

fidelity of the solution desired, which determines the level of detail required. So called "reduced order models", which approximate components or systems by aggregation of complex effects into simpler behaviors, are particularly important in multi-disciplinary situations or where complex systems are addressed. The point is that modeling must be carried out with the end goals and user needs in mind; these shape the approach and level of sophistication required.

Below are fundamental issues involved in using modeling and simulation as core intelligence next-generation product design, manufacturing, and service.

- Digital Product and Process Modeling for *Predictability*

With the increasing competitive short product development and realization cycle, all decisions involved in product and process synthesis necessitate high fidelity modeling and simulation process to validate physics-based or behavior-based design attributes. The effective use of modeling tools for dynamics, thermal, mechanics, material, and behavior systems are the prerequisite of tomorrow's digital manufacturing. These models and knowledge need to be shared in a networked and collaborative environment. The most recent SGI workstation is capable of solving intensive engineering problems in minutes and hours. For example, the proper use of ProCast FEM simulation tools enable engineers to visualize possible cracks of casting parts due to thermal variation in the manufacturing process. As a result, the manufacturer can use well-engineered simulation models to assist suppliers in changing the mold design and delivering near-zero-defect casting parts to customers that will minimize reworks and defects.

- Materials *Producibility* and Affordability

Fabricating materials affordably is always a challenge to the manufacturing industry, in particular, the aerospace industry. With more stringent regulations and constraints in environment and performance (i.e. buy and fly ratio), companies are looking for better super alloy high-temperature materials and near-net-shape processing technologies to reduce the costs of raw materials and manufacturing operations. Currently, most research tools and process models in the research community are inadequate for companies to predict and validate material properties in the manufacturing processes. For example, the machining of Ti-based aerospace parts necessitates performance monitoring the material properties in the production process. Labor intensive and repetitive measurements are required to assure quality and reliability. These certainly impact the stretch goals in affordability and performance. More research activities are needed to address on-line residual stress measurement of materials properties during manufacturing processes. We must expand our monitoring focus from dimensional accuracy to materials performance to obtain a full understanding of the quality of the processes, machines, and parts. This will lead us to forge an interdisciplinary research practice in integrated materials, manufacturing, physics, and computation to advance our understanding in manufacturing science.

- Variation and Quality Control for *Productivity*

Smart production systems are needed to monitor process variations to achieve high quality operations at lower costs. Methods must be developed for an adaptable and reliable intelligent process control software that include real-time and on-board models consisting of machine, process, material, and environment. These methods must deal with production variation and guarantee process and product quality globally through an integrated ERP system. To better enable modern process industries to control process variations, system features such as reconfigurability, reusability, self-learning, and knowledge transferability need to be added to the sensors and process control system.

- Green Products and Processes for *Pollution Prevention*

New imperatives are needed to allow sensors and process control technologies to be better *integrated to provide improved energy efficiency and reduce waste with lower development and installation costs. The green manufacturing system (i.e. green factory) should be developed to enable the plant to monitor process parameters and acquire true process information directly, accurately and quickly. In addition, alternative chemical-based coating technologies are needed to impact chemical free manufacturing processes. Innovative sensors are also needed to monitor and control chemically corrosive environments. Emerging technologies such as the micro-electro-mechanical (MEMS) based process sensors and wireless communications need to be developed and engineered to meet these challenging needs. In addition, innovation on green product design is needed to change the physics of product functions and eliminate manufacturing and remanufacturing as much as possible (for example, a motorless vacuum cleaner or a compressorless air conditioning system).*

- Advanced Maintenance Technologies for Product and Process *Performance*

Service and maintenance are important practices to maintain product and process quality and customer satisfaction. The recent rush to embrace computer-integrated technology in manufacturing industries has further increased the use of relatively unknown and untested technology. Difficulty in identifying the causes of system failures has been attributed to several factors, including system complexity, uncertainties, and lack of adequate troubleshooting tools. Currently, many manufacturing industries are performing service and maintenance activities still based on a reactive approach. The fundamental issues that prevent us from resolving these problems are an inadequate understanding of the behavior of manufacturing machine and equipment on a daily basis. We simply do not know how to measure the performance degradation of components and machines. We lack the validated predictive models and tools that tell us what would happen when the process parameters take on specified values. Research is required to understand the factors involved in product and machine breakdown and develop smart and reconfigurable monitoring tools to reduce or eliminate production downtime, and reduce dimensional variation due to process degradation. To achieve these goals, smart software and NetWare are needed to provide proactive maintenance capabilities such as performance degradation measurement, fault recovery, self-maintenance, and remote diagnostics. These features would allow manufacturing and process industries to develop proactive maintenance strategies to guarantee the product and process performance and ultimately eliminate unnecessary system breakdowns.

3. Needs in Web-enabled Product Design, Manufacturing, and Service

Discrete product manufacturers are under pressure from customers (and the market) to move away from the traditional *make-to-stock* production model to a *build-to-demand* model. Many customers are no longer satisfied with mass-produced goods. They are demanding customization and rapid delivery of innovative products. In addition, regulatory agencies now impose more constraints on product makers – thereby demanding more while companies have less resources to meet these requirements. The current method of designing a mechanically engineered product is for a designer with knowledge of design rules, product specifications and manufacturing preferences to evolve a design. Today's CAD systems do not allow direct imposition of multi-disciplinary preferences regarding functionality, manufacturability, assemblability, safety, reliability, ergonomics, material, and other issues against which such products should naturally be tested. Furthermore, the downstream activities such as maintenance cannot be directly addressed during the design process.

Another problem that has become more noticeable is the supplier selection mechanism. The current selection mechanism assumes that candidate suppliers have been short-listed and then are subjected to a number of attributes, performance metrics, and even decision models. However, the technical capability of suppliers tends not to be available at the product design decision stage. This makes it crucial that a

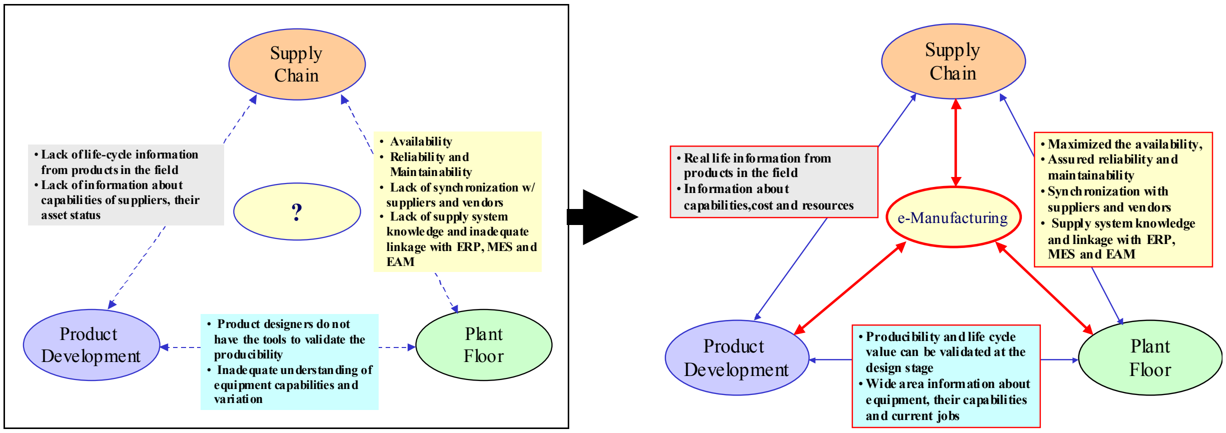

Figure 2: The transformation of e-Manufacturing for unmet needs

methodology be developed for including the supplier to participate in product development process and to demonstrate the framework through a prototype web-based platform on the Internet/Intranet using web technology. Another issue which is currently difficult to address because of the current approach to design on the CAD is the ability to capture how humans interact with devices and machines. Complicated physical simulation systems are sometimes built to address this shortcoming. Modular tools that instantiate characteristics of behavior and physics should now be embodied in a new design platform.

With emerging applications of internet and tether-free communication technologies, the impact of e- intelligence is forcing companies to shift their manufacturing operations from the traditional factory integration philosophy to an e-factory and e-supply chain philosophy. It transforms companies from a local factory automation to a global enterprise and business automation. The technological advances for achieving this highly collaborative design and manufacturing environment is based on multimedia type information-based engineering tools and a highly reliable communication system for enabling distributed procedures in concurrent engineering design, remote operation of manufacturing processes, and operation of distributed production systems. As shown in Figure 2, e-manufacturing fills the gaps exist in the traditional manufacturing systems. The gaps between product development and supply chain consist of lack of life cycle information and lack of information about supplier capabilities. Hence, designers, unless with years of experience, work in a vacuum, design the product according to the specification given, and wait for the next step. Most of the time, the design made according to specifications is realized to be infeasible for manufacturing with suppliers' machinery. As a result, lead time become longer. Similarly, for instance, because of the lack of information and synchronization between suppliers and assembly plants, just-in time manufacturing and on-time shipment becomes possible only with a substantial amount of inventory whereas with e-manufacturing, real-time information regarding reliability and status of supplier's equipment will be available as quality information of products will be. With this information and synchronization capabilities, less and less inventory will be necessary contributing to the profitability of the enterprise.

The intrinsic value of an e-Manufacturing system is to enable real-time decision making among product designers, process capabilities, and suppliers as illustrated in Figure 3. It provides tools to access life cycle information of a product or equipment for continuous design improvement. Traditionally, product design or changes need to take weeks or months to be validated with suppliers. With the e-Manufacturing system platform, designers can validate product attributes within hours using

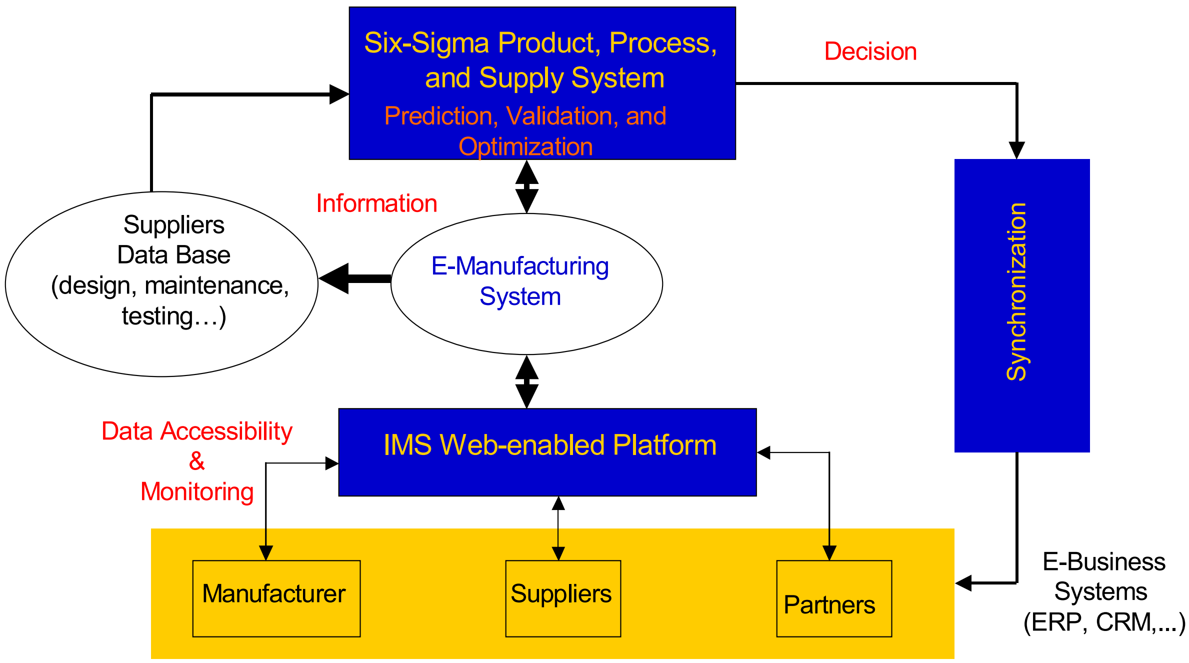

Figure 3. Using e-Manufacturing for Product Deign Validation

the actual process characteristics and machine capabilities. It also provides efficient configurable information exchanges and synchronization with various e-business systems.

Future Direction

A revolutionary design paradigm should be evolved whereby a design platform can call on design tools over the Internet. This requires that there be research and development of a scalable, flexible, and efficient collaborative *e*-product realization platform which allows a customer and a manufacturer to work on a product concurrently, and to provide the customer, in virtual space, the capability to specify preferences which then impose domain specification constraints on the product and the product's components. It will allow for multidisciplinary product design evolution. For example, by selecting a certain type of material, the designer has shown preference for the material and the physical properties of the material can be automatically instantiated as design constraints due to the material preference. These material properties would now constrain the material to perform in predictable ways under stress and similar loading conditions. Such analysis should be transparent to the designer within the design platform. The architecture will also ensure that interaction between the customers—wherever the customer may be—and the designer/manufacturer of the product is transparent. This concept reduces design time significantly and removes the need for many design iterations and visits to vendor sites in the realization of a product. It is envisaged that future CAD systems will adopt the *e*-Product realization approach in product conceptualization, and design. It will become significantly easier for customers to communicate their product ideas to their manufacturing vendors, and OEMs. Higher-level decision makers can easily play "what-if" scenarios necessary to make business decisions about products.

Currently, an One Day Design Studio (ODDS) has been established at Shanghai Jiao Tong Univ. in partnerships with over 12 global companies, including Intel, GM, Rockwell Automation, Microsoft, Toshiba, Fujitech, Askew, Hailer, Shanghai Electric, etc. as well as a number of research institutions including Xian Jiao Tong Univ. Tsinghua Univ., etc. The vision of ODDS is to product an informatics platform for rapid product design and manufacturing validation. Designers, customers, and suppliers can use a networked modeling and simulation tools to evaluate, synthesize, and optimize various options and make final decision within day(s).

The Benefits of a Unifying Research Agenda

Due to the shrinkage of in-house R&D nationally in industries, it has become crucial for companies to have an avenue for outsourcing R&D to insure that they remain competitive and are able to maintain short cycle-time development and short life-time products. Industry needs more "windows" on rapid developments occurring in mechanical product production. These advances, however, require very expensive integrated basic research and development which can no longer be afforded by individual companies. A research will serve as the unifying entity to promote collaboration in achieving synergy in developing cost effective and innovative tools which integrate to result in the realization of e-product design platform. The following is a summary of expected benefits:

- Customers can directly interact with the system. They can define their case-by-case specifications that are unique or have engineered-to-order content. The customer directives are then translated into functional constraints by the system and eventually result in the manufacturing of specialized product that a specific customer needs.
- Tying together the multitude of heterogeneous and geographically dispersed computing systems as well as multidisciplinary design participants.
- Involving suppliers/vendors in product development and virtual prototyping of product.
- Ability to design components and assemblies using a user-friendly platform.
- Ability to impose the multidisciplinary design preferences and constraints directly under one platform
- Ability to perform design tests such as computational fluid dynamic tests using third party analysis package in a transparent manner within the design platform.
- Providing domain specific design constraints in mathematical form for FAA, FDA and OSHA rules at design stage instead of consequently upon design completion for chosen product domain.
- Ability to innovate products that customers want and for which sourcing can deliver. This allows multiple enterprise constituents and customers to participate on a real time basis during product design -- thus islands of knowledge can be effectively brought together on a global basis under one platform. This guarantees that supply-chain decisions are incorporated in the design process.
- Faster time to market.

A networked research centers will also:

- Provide unique opportunities in research and education which provides engineers with state-of-the-art training that is currently unavailable in integrated web-based product design and realization.
- Develop and manage a decision making structure that brings together capabilities for critical analyses and enables support for appropriate research activities.
- Develop, manage and distribute financial support for appropriate research.
- Disseminate the results of sponsored research to the mechanical products industry.
- Bolster academic institutions by maintaining the organizational means through which the private and public sectors can identify and support pertinent research challenges.

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