Procedia Manufacturing
Volume 5, 2016, Pages 182–194
44th Proceedings of the North American Manufacturing Research Institution of SME http://www.sme.org/namrc

Developing the Digital Manufacturing Commons: A National Initiative for US Manufacturing Innovation

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Abstract

The manufacturing sector is at the core of the American economy. With American leadership in advanced manufacturing at risk due to changes in the global economy and new competitors rising across the globe, the U.S. President announced an investment of $1 billion in a National Network for Manufacturing Innovation (NNMI). The key focus is on new technology paradigms that can improve the competitiveness of American manufacturing – with a focus on small and medium enterprises (SMEs) – through digitization of design and manufacturing, democratization of technology, and collaborative design and analytics to sustain leadership across the U.S. manufacturing ecosystem.

Funded through the newly established Digital Manufacturing and Design Innovation Institute and supported through a Cooperative Agreement with the Department of Defense, the Digital Manufacturing Commons (DMC) is an open-source platform based on previous Massachusetts Institute of Technology (MIT), Defense Advanced Research Projects Agency (DARPA) and General Electric (GE) projects and built to democratize development and access to the tools for manufacturing innovation across small and large companies, universities, institutes, and entrepreneurs. The DMC will bring together one hundred thousand or more users, thousands of SMEs, large manufacturing companies, and universities to collaborate on manufacturing and to accelerate technologies that integrate the digital thread from design to manufacture and service.

The initiative to build the DMC is led by GE Global Research Center. The DMC will be transitioned to the Digital Manufacturing and Design Innovation Institute and made available to the U.S. manufacturing base to enable a digital revolution in manufacturing innovation.

Keywords: Digital Manufacturing, Collaboration Platform, Business Models

 Selection and peer-review under responsibility of the Scientific Programme Committee of NAMRI/SME

doi:10.1016/j.promfg.2016.08.017

1 Introduction

The Digital Manufacturing and Design Innovation Institute (DMDII) is the nation's flagship research institute for applying cutting-edge digital technologies to reduce the time and cost of manufacturing, strengthen the capabilities of the U.S. supply chain, and reduce acquisition costs for the Department of Defense (DoD). The Institute will address the life cycle of digital data interchanged among a myriad of design, engineering, manufacturing and maintenance systems, and flowing across a networked supply chain. Applications that address these challenges will make up the digital thread, and will provide the next wave of productivity improvements.

One of the foundational elements of DMDII is the Digital Manufacturing Commons (DMC). The DMC is a key to digital manufacturing innovation because it allows for integration of data across the digital thread. The DMC facilitates system engineering by linking digital information and data across the entire product life cycle and supply chain. Within the DMC, experts and non-traditional contributors can design components or systems by reusing, remixing, and augmenting designs prepared by others. These designs can continue to evolve through a series of reiterative design loops. figure 1 shows the different DMC users and how distinct models, public or proprietary, can be integrated.

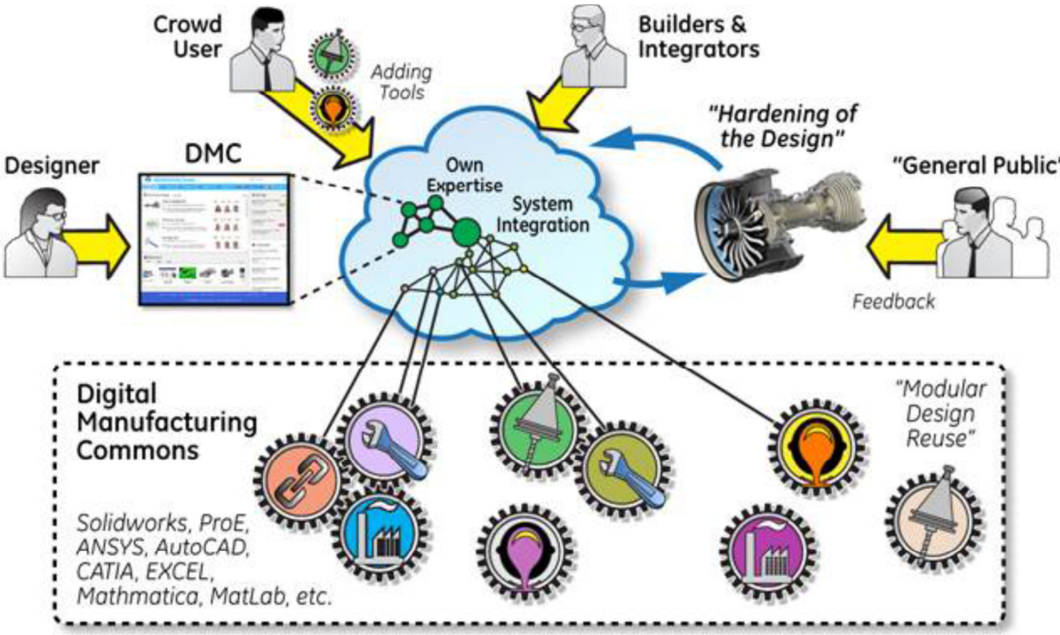

Figure 1. Digital Manufacturing Commons: actors, tools and model integration

Traditionally designs or products were at the core of a company's prosperity, nowadays effective use of the supply chain as well as lean manufacturing practices, agility, data management, are the critical differentiators, given that quality is assumed (Malghan, Rao, & D'Souza, 2013). A search for differentiating capabilities lead to the formation of web-based collaboration platforms where different life cycle phases can be integrated. A similar concept is cloud-based design and manufacturing (CBDM). CBDM refers to a new manufacturing paradigm that enables rapid product development at low cost through Internet-based services such as social networks and negotiation platforms (Wu, Rosen, Wang, & Schaefer, 2015). Key areas of differentiation for the DMC are: 1) It is a collaboration platform capable of performing sophisticated engineering tasks, 2) It can run advanced simulations, 3) It is a free and open source, 4) It is hosted, managed and maintained by DMDII, an industry-neutral, trusted third party institute.

The rest of the paper is organized as follows. Section 2 describes the previous projects and initiative that lead to the Digital Manufacturing Commons. Section 3 introduces how the technology behind the platform is an enabler for disruptive business models and a force for creative destruction. Section 4 presents the DMC, its advantages and the main features. Finally, section 5 presents our vision.

2 Background

The DMC is the result of a vibrant ecosystem of different parallel activities aligned with collaboration and innovation in manufacturing. The realization that U.S. leadership in manufacturing is under threat from competing international markets emphasized the need for such platform. To promote U.S. manufacturing competitiveness SMEs, government, and large industrial stakeholders need an ecosystem that allows them to innovate at a faster pace; producing new products more quickly at lower costs and higher margins.

The DMC platform supports the democratization of design and manufacturing model development by providing an open virtual environment where models and their tests can compete for prominence. It provides a marketplace where contributors, both small and large, can publish models while maintaining ownership, integrity and preserving value. The DMC establishes an open-source model repository where models can be collaboratively developed and matured. It ensures ample levels of security through federated authentication and authorization. In essence it cultivates the emergent synthesis of design models by empowering participants through distributed interoperable software service interfaces.

2.1 Digital Manufacturing and Design Innovation Institute

In June of 2011, a report of the President's Council of Advisors on Science and Technology (PCAST) (Executi, 2012) gave recommendations and outlined approaches for domestic manufacturing innovations to improve U.S. global competitiveness. The report states that American leadership in advanced manufacturing is at risk and provides recommendation in three areas: 1) enabling innovation, 2) securing talent pipeline and 3) improving business climate. The report includes a call to establish a National Network of Manufacturing Innovation Institutes (NNMII).

In March 2012 President Obama (The White House, Office of the Press Secretary, 2012) announced $1 billion in investments to support U.S. manufacturing innovation and encourage insourcing. Within this National Network for Manufacturing Innovation (NNMI) up to fifteen new institutes for manufacturing innovation are being built around the country. The Departments of Defense, Energy, and Commerce, the National Science Foundation, and NASA invested in a pilot institute, the National Additive Manufacturing Innovation Institute (NAMII), now known as America Makes. The institute includes private companies, research universities, community colleges and nonprofit organizations and is managed by the National Center for Defense Manufacturing and Machining (NCDMM) (NCDMM is Chosen to Manage National Additive Manufacturing Innovation Institute (NAMII), 2012).

One year later, in January 2013 the Executive Office of the President, National Science and Technology Council, Advanced Manufacturing National Program Office describes the NNMI as a linked set of Institutes for Manufacturing Innovation (IMIs) (Executive Office of the President, National Science and Technology Council Advanced Manufacturing National Program Office, 2013) each with a unique focus, but the common goal to achieve innovation across U.S. manufacturing processes. The NNMI program is managed by the interagency Advanced Manufacturing National Program Office (AMNPO) that includes the Departments of Defense, Energy, Education, Commerce, National Institute of Standard and Technology (NIST), NASA, National Science Foundation and others (How NNMI Works).

A request for information for a Digital Manufacturing and Design Innovation (DMDI) Institute was issued in May 2013. In July of the same year the Digital Manufacturing and Design Innovation Institute was presented as a resource to improve U.S. manufacturing competitiveness (Gregory A. Harris, 2013) and the institute proposals were submitted in October of the same year. In February 2014 president Obama announced the DMDII winner, a Chicago based consortium led by UI LABS. The institute was funded with a $70 million federal investment, more than matched by nonfederal partners (RDECOM Public Affairs).

A major commitment of DMDII is to support the development and implementation of the Digital Manufacturing Commons as a tool to revitalize American manufacturing and its international competitiveness. The DMC is based on software that GE Global Research Center (GE GRC) had developed for a previous project called Crowd-Driven Ecosystem for Evolutionary Design (CEED). The software is open source, and long term operations will be handled by DMDII. The operational infrastructure leverages GE‘s extensive experience in developing and supporting web-based project collaboration platforms and MIT‘s research accomplishments around distributed collaborative design environments. It also builds on multiple established open-source software systems and applications.

CEED was a joint GE GRC-MIT effort to build a crowdsourcing platform to support Defense Advanced Research Projects Agency’s Adaptive Vehicle Make (AVM). The goal of AVM was to compress the development timelines for new complex cyber-physical systems by at least five-fold. The goal of the platform is to change the manufacturing model to be more dynamic and competitive. The vision of CEED is to host a marketplace for design and manufacturing service models. CEED was based on an ongoing MIT project called Distributed Object based Modeling Environment (DOME). MIT’s DOME is a platform to create models and services that can be integrate with each other, and coined the concept of a worldwide simulation web and together with this team developed DOME to enable this vision (Wallace, Abrahamson, Senin, & Sferro, 2000).

3 Business Model Innovation

The DMC is, at its core, a platform for business model innovation; the technology behind it is an enabler for disruptive business models and a force for creative destruction.

Sometimes called Schumpeter’s gale, creative destruction is a theory of economic innovation and the business cycle (Schumpeter, 1942) that describes how new economic orders are continually created and prior economic orders are continually destroyed. Much study has been given to understanding the phenomenon of creative destruction since Schumpeter‘s original work was published in 1942 (Schumpeter, 1942).

Online marketplaces and widespread connectivity have led to the rise of numerous collaboration platforms, typically using a Multi-Sided Platform (MSP) business model. MSPs, such as Uber, Facebook, and Groupon, bring together two or more groups of customers that have interdependencies. This is a very different paradigm than traditional operating modes for a company (e.g., vertically integrated firms, resellers, or input suppliers), with one of the biggest differences being indirect, or side-channel, network effects (Hagiu & Wright, 2015).

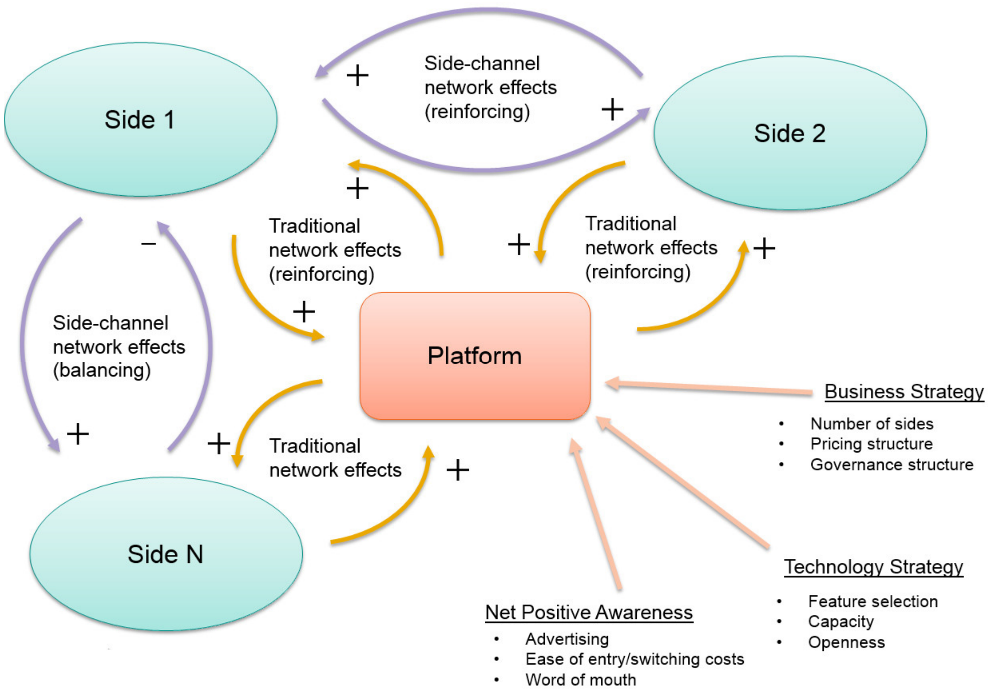

Figure 2. Multi-Sided Marketplace with both direct and side-channel network effects (Barkley, 2016)

MSPs are an emergent phenomenon in many sectors of the economy, and the digital shift in manufacturing is rapidly changing the way companies do business. MSPs are accelerating and changing the cycles of creative destruction and are inherently unpredictable, largely due to complex dynamics. A simple representation of this business model is shown in figure 2. At its core, the DMC consists of three major elements to support the emergence of MSPs in design and manufacturing:

1. **Core Collaboration Platform**. The core collaboration platform is a web-based collaborative environment that manages users, data, and models. File management, project management, and collaboration tools are a few of the key features.
2. **Data**. Data includes engineering artifacts (e.g., CAD files), documentation (wiki, pdf, etc.), part metadata (e.g., suppliers, materials), and machine performance statistics. The DMC is distributed, allowing data, models, and users to reside in any location.
3. **Models**. A model is any executable code, scripted code, or any other dynamic or parameterized analysis. Models are encapsulated in a standard format so that they can be run in a Software-as-a-Service (SaaS) paradigm.

When users are enabled to combine these three basic elements, the effects are powerful, and lead to what we call the distributed commons. The distributed commons is designed to enable model reuse and sharing across a network. It is an environment where users can: publish data and models; exchange data, models, services and opportunities; and build their reputations.
The service cloud (Samimi, McKinley, Sadjiadi, Tang, Shapiro, & Zhou, 2007) allows users to run models on live data in near-real time. It also allows users to compose complex value chains by encapsulating multiple models and services in a packaged executable workflow.

3.1 Transformation of Business as Usual

In the ecosystem enabled by the DMC, new ways of doing business which were previously infeasible now become possible. The manufacturing sector in the U.S. has a very long tail of Small and Medium Enterprises (SMEs) who have traditionally been unable to afford the investment required to use complex software tools for advanced analysis. These tools can be cost-prohibitive for an SME, not just in the licensing costs, but also in the maintenance burden of keeping a trained staff of engineers with knowledge of how to use these tools. An unfortunate effect of this situation is that software vendors have had a hard time tapping into that long tail of U.S. manufacturers as an impactful revenue source, which consequently impacts their pricing and business models.

The academic and non-profit communities are a frequent source of new research along with many of the larger players in industry and a few of the smaller, more aggressive manufacturers, but these efforts often wither on the road toward commercialization. Often research technologies make it as far as a proof of concept or laboratory production, which is a Technology Readiness Level (TRL) (EARTO, 2014) of three or four; however, industry typically needs a TRL of seven or higher to be able to have a viable commercialization strategy. The challenge of getting new technologies from a TRL three or four to a TRL seven or higher is often referred to as the *Scale-up Gap* or *Missing Middle*, and is illustrated in figure 3. One of the barriers is the challenge of sharing data, technologies, IP, standards.

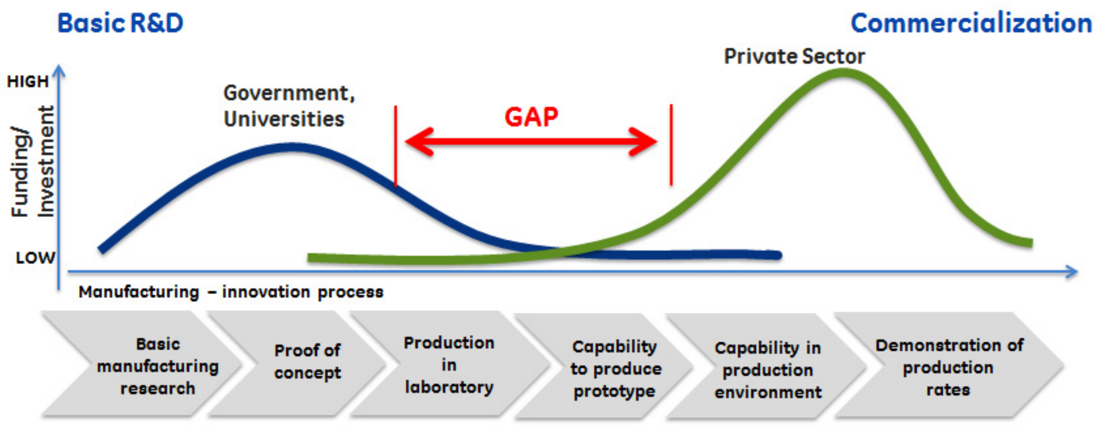

Figure 3. The Scale-up Gap or Missing Middle (United States Government Accountability Office, Report to Congressional Requesters, 2014)

The DMC makes it not only possible, but easy to get new research concepts into the hands of people who can evaluate, find a niche use case, or take it to the next level. For students and researchers, it provides a place to publish and showcase technology demonstrations, and for big software vendors the DMC provides a lightweight mechanism to test out new concepts in the marketplace. This marriage between impassioned and hedonically motivated lead users, and the more utilitarian-motivated incumbents is a powerful way of bringing innovation from the edges and getting them into the realm of commercialization.

For SMEs, the DMC provides a way to get access to tools that are otherwise unaffordable; furthermore, the nature of the DMC with a standard, parameterized web interface provides a transition pathway to Software-as-a-Service business models for traditional large software products. Standardizing these service packages and interfaces enables something that has never been done on a large scale before: the ability for end users to synthesize multiple services into a single, integrated software product, see figure 4.

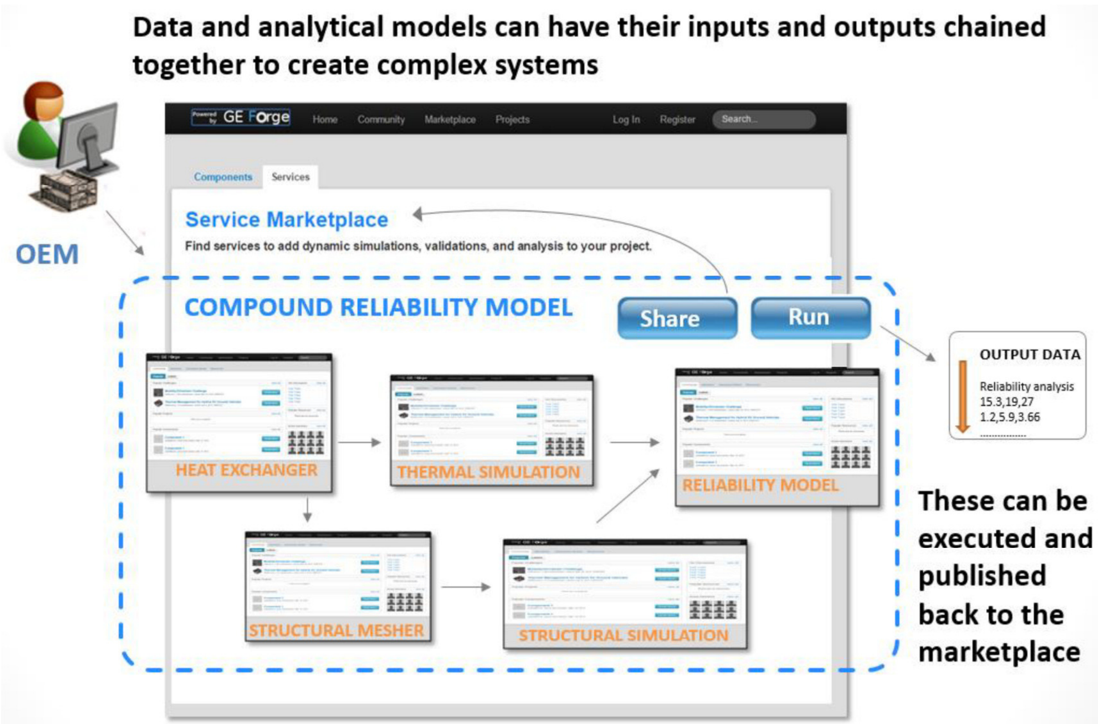

Figure 4. Example of integrating a model from five existing models

This is transformative from a business model perspective, because it allows for innovation in a number of ways that can provide value to all actors along a service chain. Here are a few examples of potential new business models:

- **Pay by algorithm execution (Software-as-a-Service)**. In this case, an end user may simply pay a fixed price to run an algorithm on their data. As an example, an algorithm that estimates the volume and cost of filament for a manufacturing process could be run on a STEP file for $10.00.

- **Pay by resource consumption**. The user is charged per unit of service. In this case, the value to an end user may be the ability to run computationally-intensive algorithms on large scale infrastructures. This would reduce initial investments on infrastructure, reducing disadvantages for SMEs. As an example, an end user may pay $70.00/hour to run a complex Finite Element Analysis (FEA) at a supercomputing center. One interesting aspect of this use case is that the actual algorithm being run could come from the user, the supercomputing center, or a third party partner like a software vendor; one can imagine all of the different ways that payment distribution could happen.
- **Chargeback integration**. A software startup would synthesize interesting models they find in the marketplace into a novel new software service, and then charge for it. As an example, they might take an open source auto-mesher and combine it with an industry standard structural FEA tool. The seller that is getting paid by the user for the integrated service is using some free and some proprietary software. The chargeback occurs by negotiating beforehand a charge which will go to the vendor of the proprietary software.
- **Freemium SaaS**. The vendor could simply offer a limited capability in the marketplace for people to use freely; however, to run a higher-fidelity version a payment model would be applied. For example, a cost-estimation algorithm for producing a specific part could be offered freely, which returns only a final dollar amount. If more detail is desired, the user can pay $15.00 a month for the premium version of the service which returns a breakdown of estimated costs by Bill of Materials, filament, energy consumption, and operator time.

The Digital Manufacturing Commons has the ability to bring together SMEs, large enterprises, software vendors, researchers, and intermediaries into an ecosystem in which participation is mutually beneficial. The development and hosting by the DMDII yields the advantage of providing social cohesion in this ecosystem due to their trusted 3rd party status.

4 The Digital Manufacturing Commons

In this section we list some of the advantages of the DMC together with its features.

4.1 DMC Advantages

An important consequence of the way the Digital Manufacturing Commons is designed and implemented is a set of unprecedented advantages.

Cloud Based. The DMC is cloud based. The DMC platform architecture is cloud based. A recent paper (Banarjee, et al., 2015) explains details of the cloud implementation. It runs on multiple third party cloud providers infrastructure or on similar products. It uses automated geographically dispersed failover protection. It is able to run on an ITAR-compliant cloud. It also runs on an internal cloud, isolating it from the rest of the world.

Model Integration. The DMC enables Innovative Model Integration. A wide variety of different models can be combined within the DMC. Proprietary models and models found in the marketplace can be merged into more complex models. Models found in the marketplace are accessible through a public interface while the model details remain hidden. DOME, the underlying model builder software, supports a large variety of models through plug-ins. DOME allows developer to jointly design models. They can use different development tools and can share information without losing proprietary data. DOME addresses the massive software and structural complexity of new cyber physical systems.

Open Source. The DMC code-base, in deployment and application, is open source, with no claim on IP rights in perpetuity. This refers to DOME source code as well as web source code. Code contributions are managed by branch and pull request. All new code developed for the DMC platform will also be open source. The open source license allows users to modify or add to the code without restriction. Users are able to write their own additions and modules. The licensing enable user generated code to be made open source or be owned by the author. DMDII will govern the contents of the open source code base.

Sustainable Design and Manufacturing. To be successful, sustainable design and manufacturing must be implemented in any step of the supply chain. With the use of the DMC products and services will be developed with reduced time, cost and resources in general. Users of the DMC will publish new, possibly proofed concept, techniques and tools that can be integrate with proprietary approaches.

Industrial Internet Promoter. We can envision the DMC being a data sink for the Industrial Internet (Evans & Annunziata, 2012), where complex machines are monitored and controlled by a network of sensors. Industrial Internet is growing into reality and machines are highly connected, factory data could be sent to the DMC for access, monitoring, control.

Advanced Identity Management. Off-the-shelf systems will be augmented with capability to handle export-controlled information and federated authentication and authorization. Secure identity passing will be provided by InCommon, with social media login (e.g., LinkedIn) provided by Cirrus Identity. These features will support user and project security. The security solution will be built on freely available and established open-source software, such as Shibboleth.

Security Solutions. Third-party security assessment and functionality testing was conducted to ensure compliance with existing NIST and ISO standards. A 3-phase penetration test (pentest) targeting the DMC website and related application services was performed. It comprised of 1) passive opensource intelligence gathering, 2) active vulnerability assessment of the website, and 3) active exploitation attacks. Each vulnerability was assessed both in terms of impact and likelihood.

The amount of information that is exchanged between companies, Original Equipment Manufacturer (OEM) and suppliers for example, is decided by each party. The interface of a model can be public for other to use while the underline model is not disclosed. This powerful feature also addresses the problem of security and confidentiality in an open source and cloud environment.

Workforce Training. Students can use the DMC in academia setting and evaluate the efficiency of the technology. Students can display their resume and portfolio of digital manufacturing projects.

4.2 DMC Features

We introduce four different features of the DMC, the dashboard, the community page, the project page and the marketplace. The home page is shown in figure 5.

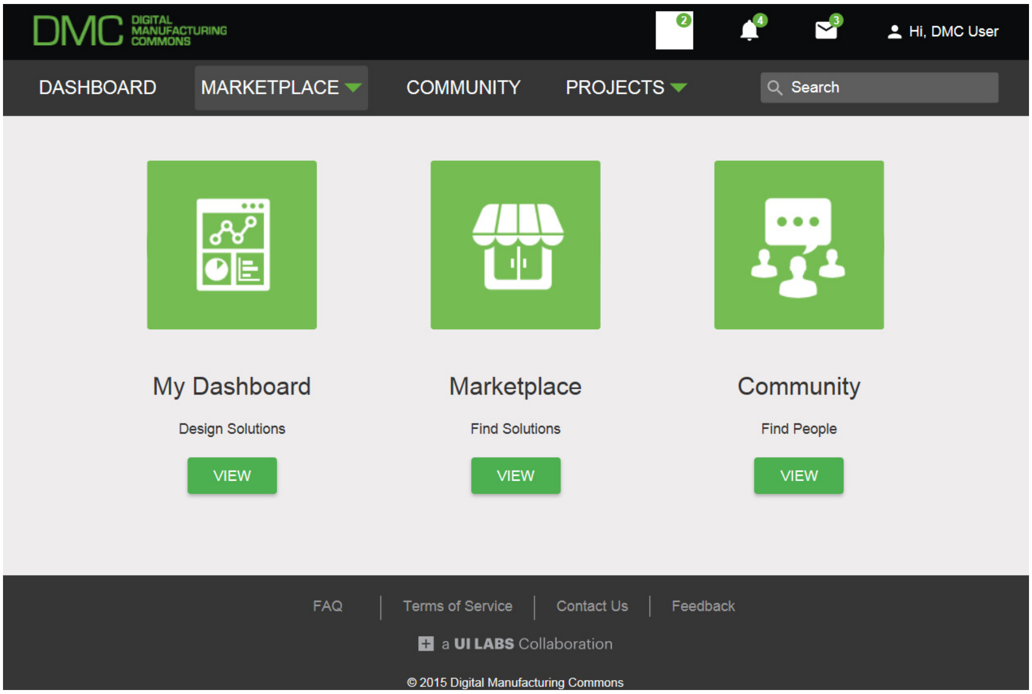

Figure 5. opendmc.org is the main page for the Digital Manufacturing Commons

Dashboard. DMC user dashboard contains a summary of the member's activity. It presents one-stop management of manufacturing projects and provides recommendations of relevant engineering tools and models, a list of tasks and discussion. A dashboard page has active projects and the people involved in each project, a task section, a discussion section and the favorite links in the marketplace.

Community. The community page lists the subscribed discussions, the members, the people followed and a search window.

Project. This section enables the creation of private projects with specific tasks, discussions, services and components. A project can be shared with collaborators in the team or with others to create challenges. Data and models can be added to projects.

Marketplace. The marketplace, figure 6, enables the democratization of the design, engineering and manufacturing through collaboration, models and services. It is an ecosystem that allows individuals and companies to: 1) exchange models, services, and opportunities. Contributors can publish a model while maintaining ownership and preserving value. 2) Integrate nontraditional team members to freely express opinions, vote, test, and distribute information, 3) manage reputation building to identify high-performance individuals, 4) foster a healthy ecosystem through an iterative system of controlled selection pressure events and market-driven competition that weed out poor designs and select for robust yet unforeseen and unplanned features, and 5) facilitate democratization of hardware design.

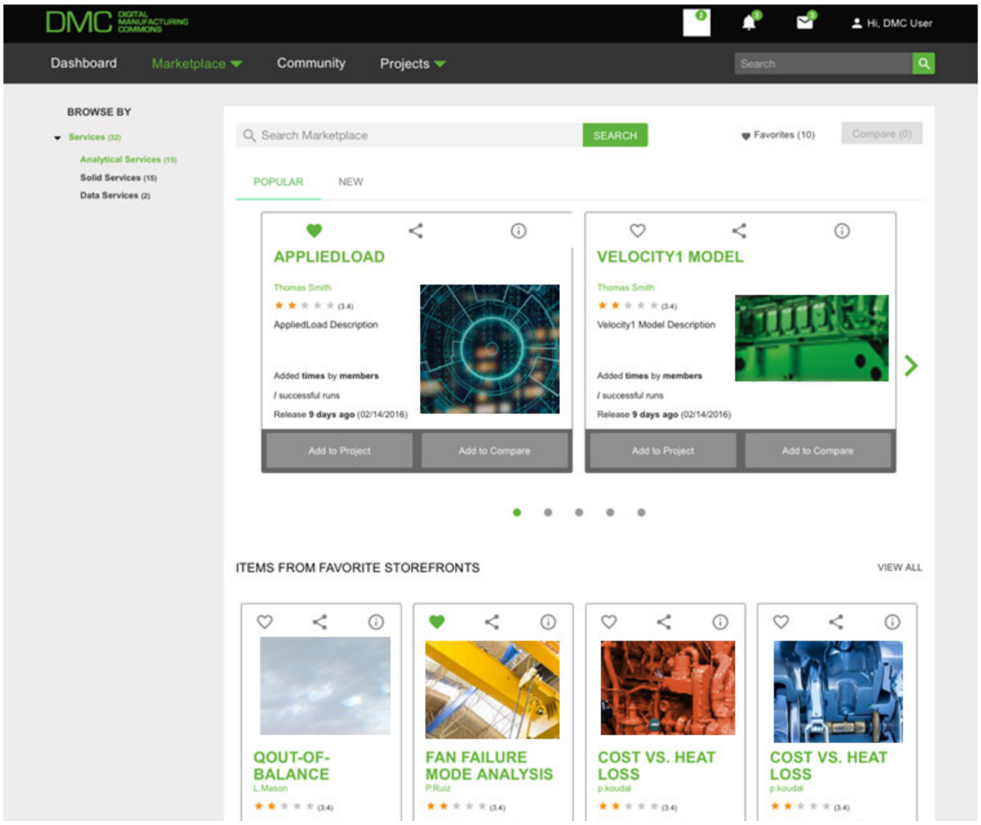

Figure 6. The DMC Marketplace

5 Future and Vision

This paper gives the background of the initiatives that lead to the creation of the DMC. It does not give details of related research or technical implementation. Development details will be presented in future publications.

Our goal is to establish and implement the core elements of the DMC as an open-source platform for secure and trusted collaboration during the design-make process and to develop an initial set of foundational applications that utilize the DMC platform. By the conclusion of a first implementation phase the DMC platform will be fully transitioned to the DMDII. As the platform matures, the team expects it to become the main platform for open-source hardware designs where experts and others share, reuse, remix, or build on design resources shared by others. The DMC will become a highly connected and collaborative network including thousands of organizations that will implement pervasive standards for advanced technical data packages across the supply chain. The DMC will allow distributed teams to collaborate within a common virtual workspace, allowing designers and makers to work together on projects by sharing data and files. The DMC will enable connections to software and analysis tools, cloud computing, and high-performance computing. The architecture of the DMC will allow for adding functionality in the form of applications from a broad DMDII community. It is envisioned that the DMC will bring together one hundred thousand or more users, thousands of SMEs, manufacturing companies, and universities to collaborate on manufacturing and to accelerate technologies that integrate the digital thread from design to manufacturing and services. The DMC will also enable the addition of functionality through the development of additional applications that utilize the core DMC engine produced by this work effort. When fully implemented, the DMC will provide a platform for inventors and developers to rapidly bring the latest innovations to the entire manufacturing ecosystem, thereby accelerating the impact of the DMDII to the U.S. economy.

Acknowledgment

This work was supported in part by the US Defense Advanced Research Projects Agency (DARPA)/Contracts Management Office (CMO) Contract No. HR0011-11-C-0092, Digital Manufacturing Design Innovation Institute Agreement (DMDII) No. 2014-434, and a Cooperative Agreement with the Department of Defense.

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