# Cloud Computing-Based Marketplace for Collaborative Design and Manufacturing

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**Abstract.** This paper introduces an open-source, interoperable platform for real-time collaboration in complex product lifecycle development across multiple companies. Each segment of the lifecycle, including product conception, design, analysis, prototyping, component sourcing, manufacturing and assembly, logistics and delivery, and services from installation to maintenance, repair and overhaul, can benefit from this collaboration through easy access, development, deployment, and integration of heterogeneous models and data. The platform is built on an elastic cloud-computing environment, which provides efficient scaling of computational performance needs to support the collaboration platform. We believe that this platform will enable organizations of all sizes to enter a new digital age of integrated product design, manufacturing and service systems.

**Keywords:** Cloud computing · Industrial internet · Internet of things · Digital manufacturing · Collaborative design · Lifecycle · Supply chain · Crowd-sourcing · Cloud-based design and manufacturing

## 1 Introduction

General Electric (GE) is one of the founding members of the Industrial Internet Consortium (IIC) [1] created in 2014 to accelerate the advancement and adoption of the Industrial Internet [2] (II). The Industrial Internet brings together industrial engineering, sensors, software, and big data analytics to create a networked system of brilliant machines. The term II was created to further expand the scope of the existing paradigm of the Internet of Things (IoT) to industrial systems. An exercise from [4] highlights that if the Industrial Internet boosted US labor productivity by about 1.5 % and by half that value in the rest of the world, Global Gross Domestic Product (GDP) output would be $15 trillion higher by 2030. This translates to an increase of 15 % over baseline projection [4].

While several Industrial Internet technologies are focused on developing connected machines and advanced analytics, new solutions are required to address


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the problems associated with storage, access, and computing needs of heterogeneous and distributed models across the product lifecycle. Such models are used in one or more of the segments of the product lifecycle including conception, design, analysis, prototyping, component sourcing, manufacturing, assembly, logistics and distribution, and services from installation to maintenance, repair and overhaul. The output of one model typically impacts the parameters of other models. For example, part geometry affects the choice of manufacturing process which in turn is constrained by what is available in the actual factories involved at the original equipment manufacturer and suppliers. However, these impacts are frequently not considered due to a lack of interaction among the model developers, users, and owners with inherently different skill sets and performance goals. This leads to many repetitive and cumbersome iterations before a successful product is built or a failed product is abandoned [5].

Hence, there is an acute need for real-time collaboration among the different model stakeholders to reduce the overall product development cost, time, and failure rate. Cloud-Based Design and Manufacturing (CBDM) [6] offers a promising solution to this need. Cloud computing is emerging as one of the major enablers for the manufacturing industry; it transforms the traditional manufacturing business model, helps it to align product innovation with business strategy, and creates intelligent factory networks that encourage effective collaboration [20]. With cloud computing, users have access to Hardware/Software as a Service (XaaS) on a pay-as-you-go basis. Thus, there is no need for capital expenditure. Storage capacity is unlimited. Backing up data and restoring it is easy. Thus, it affords a natural service for collaboration and crowdsourcing, where a group of people within and across companies can work on the same project with access to unlimited information and the ability to connect to the Industrial Internet on a global scale.

Cloud-Based Design and Manufacturing refers to a networked design and manufacturing model that exploits on-demand access to a shared collection of diversified and distributed resources to enhance efficiency, reduce product lifecycle costs, and allow for optimal resource allocation in response to variable demand [6]. References [6,7] compare Cloud-Based Design and Manufacturing (CBDM) with traditional collaborative design and distributed manufacturing systems.

In addition, cloud computing enables scale and elasticity, two essential elements of the evolving nature of the Industrial Internet. To address the computing and networking needs of many engineering organizations, manufacturers, suppliers, and other stakeholders, cloud computing offers an affordable and efficient strategy to ensure a continued competitive edge. A summary of benefits and limitations of cloud computing for cloud manufacturing is presented in [19].

This paper introduces a platform called Digital Manufacturing Commons (DMC) [8] that uses the cloud as the infrastructure to integrate design and manufacturing models. The DMC provides an open-source platform for real-time collaboration during the design-to-manufacturing process. This new system requires a cultural change in the manufacturing industry that we believe is the key for growth opportunities. This project builds upon a previous Defense Advanced Research Projects Agency (DARPA)-sponsored General Electric/Massachusetts Institute of Technology joint effort called Crowd-driven Ecosystem for Evolutionary Design (CEED) [10]. The vision is to build a crowd-driven ecosystem for evolutionary design that connects data, design tools and simulation models in a collaborative environment to accelerate the design and development of highly complex industrial systems.

The rest of the paper is organized as follows. Section 2 presents the limits of the current manufacturing paradigm together with emerging solutions. Section 3 outlines the architecture, cloud deployment, and cyber security aspects of the Digital Manufacturing Commons. We conclude by summarizing the benefits of the proposed system in Sect. 4.

## 2 Design and Manufacturing Trends

Manufacturing has faced a number of significant challenges recently. In a consumer driven world, manufacturers need to manage fast paced innovation. Traditional ways of building things must be replaced by more flexible approaches. But often manufacturing organizations, particularly Small and Medium size Enterprises (SMEs) are not ready for this change, limiting their participation to a few segments of the product lifecycle instead of the entire lifecycle chain.

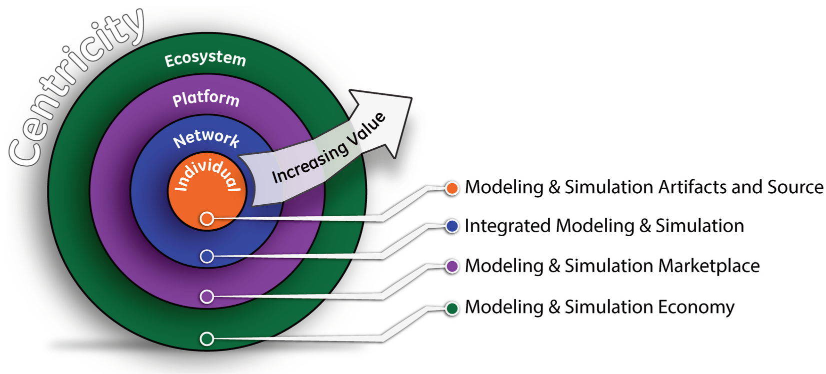


**Fig. 1.** Evolving paradigms for digital manufacturing

A shift in manufacturing that can help SMEs is co-development and crowdsourcing. With co-development, more participants can contribute ideas to the product development process. Figure 1 shows how modeling for design and manufacturing is evolving from stand-alone tools to an interconnected ecosystem. Metcalfe's law [11] establishes a critical mass after which networking and collaboration bring increasing value as exemplified by consumer and social networks. The revolution now is about industrial networks. Traditional models, where only employees and suppliers provide services and ideas, are augmented by the crowds global knowledge base. In this new environment, organizations expand their processes with capabilities from a globally distributed community rather than just from their own employees or suppliers. This new mode of manufacturing is embraced by the DMC.

The DMC is a key to digital manufacturing innovation because it allows the integration of engineering models across the digital thread [12]. The digital thread is the concept defined by the integration of information through an enterprise's value chain, from planning to disposal. Key advantages of the DMC include: establishment of an online community that may be accessed to cooperatively develop products. Organizations can bring better products to the market at a lower cost and SMEs have access to resources that would be unaffordable otherwise.

The main contribution of our framework compared to current practice is the enablement of users to combine distributed open source and proprietary tools and models. With the Digital Manufacturing Commons proprietary manufacturing models can be made available in a manner that allows others to run the models while keeping the underlying code hidden.

## 3 DMC Platform Technical Details

We now present the collaboration marketplace, architecture and cloud deployment of the DMC. Aspects related to stability, cyber security and privacy are omitted in this paper and will be addressed in a future publication.

### 3.1 Digital Marketplace

The DMC is a software platform delivered via a networked system of systems. The marketplace is populated with an initial foundational set of models to demonstrate real-time collaboration during the design-to-manufacturing process. The new distributed marketplace allows:

- Exchange of models, services, and opportunities
- Integration of nontraditional team members to freely express opinions, vote, test, and distribute information
- Management of reputation building to identify high-performance individuals
- Fostering of a healthy ecosystem through an iterative system of controlled selection pressure events that weed out poor designs and select for robust yet unforeseen and unplanned features
- Facilitation of the democratization of hardware design

The marketplace, Fig. 2, consists of three different parts.

1. *Design*: In the DMC, users search for services that drive model execution, integrate and execute them. The users judge model accuracy and send feedback to the designer. In this way manufacturers can not only consume prebuilt models but may also sell them.

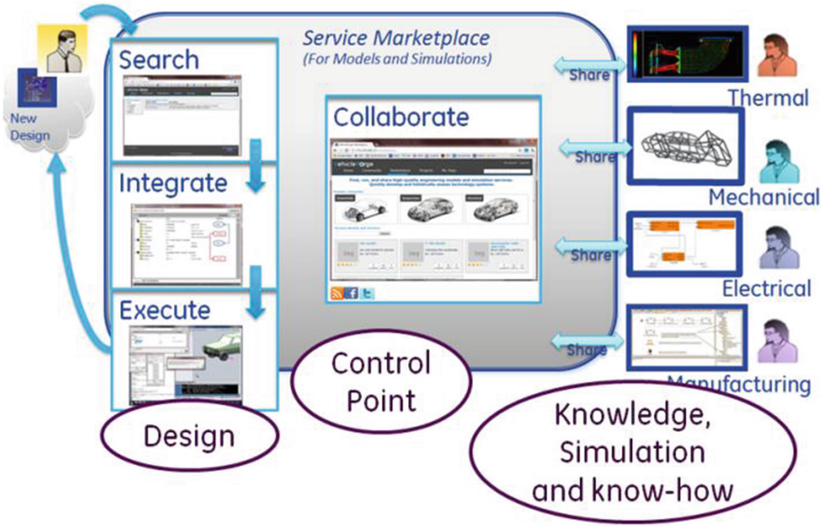


**Fig. 2.** Digital design and manufacturing marketplace

2. *Knowledge simulation and know-how*: Through the DMC, different communities of design and manufacturing engineers and other personnel can create and share projects from the most diverse domains. Complex systems can be realized by integrating disciplines into a team effort that allows an integrated design to become a part, sub-system or product. The marketplace combines information that users all over the world share.
3. *Control point*: The DMC platform facilitates the collaboration between two parties that jointly benefit from the interaction. In two-sided marketplaces customer's participation generates economic value. In fact, the DMC marketplace value depends on the number of users who publish models and users who use models. The two-sided platform is a broker through which publishers can closely interact with their customers.

### 3.2 DMC Platform Architecture

The DMC platform architecture is both *distributed* and *federated*. As expected in a distributed model, users may select whether data and models are stored locally or remotely. The DMC platform is able to connect these models so that assemblages of data and models can be linked seamlessly. The federated design of the DMC platform permits users to finely control data access permissions. DMC users are able to publish dataset metadata while maintaining restricted access to the same datasets.

The DMC platform architecture is *cloud-based*. It has automated geographically dispersed failover protection. It is able to run on an International Traffic in Arms Regulations (ITAR)-compliant cloud. The DMC platform architecture

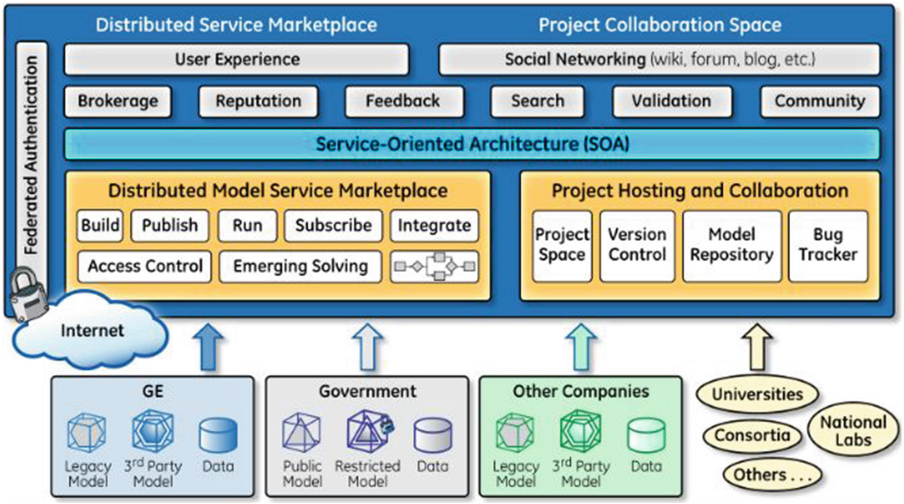


**Fig. 3.** High-level architecture diagram of the DMC

enables cloud-based execution of user generated code in a fashion which enables users to upload scripts (e.g. Python), executable files and data. It also enables users to automate and batch processes.

A high-level architecture diagram of the DMC is depicted in Fig. 3. Authentication services provide service access via a Service Oriented Architecture (SOA). This platform is an example of how SOA and cloud computing complement each other. Cloud computing provides resources to host data services and processes on demand.

The Distributed Object-based Modeling Environment (DOME) [15] is used for the creation and orchestration of models. DOME supports transparent, decentralized integration of models built using a wide variety of application tools and operating system platforms [16].

The DMC platform provides user access to externally hosted software applications through mechanisms that ensure interoperability between various data model types. The DMC platform architecture includes a data repository capable of storing and organizing data streamed from the internet of things. This data repository also allows users to store content including data and executables. In summary the DMC platform architecture enables a true 'Commons' for the design-to-make process so that:

- Users can share reusable data and executable models
- Owners of data and executable models retain rights when sharing, if desired
- Users can search for data and models
- Quantitative metrics such as availability, consistency and usage are tracked and visible
- Qualitative metrics such as community defined reputation are tracked and visible

### 3.3 DMC Cloud Deployment

An early version of the DMC was the first commercial application deployed on Amazon Web Services GovCloud [17]. The cloud environment provides an easy, low cost solution to deploy applications.

The DMC is deployed using multiple protective measures designed to secure sensitive data. Some of these measures are shown in Fig. 4. Users connect to the DMC through the internet. Public and private subnets are used to isolate internet facing services from the rest of the system. Tailored security groups are assigned to each machine instance that is deployed. Each security group restricts network traffic to specific ports from known source and destination machines. A Virtual Private Network (VPN) gateway allows communication between instances and an organization's private network.

Elasticity is another useful feature of a cloud environment. This feature allows individual subsystems to expand and contract to handle varying load levels. The DMC uses auto scaling groups to ensure a sufficient number of resources are available to handle the system load. It is possible to specify the minimum and

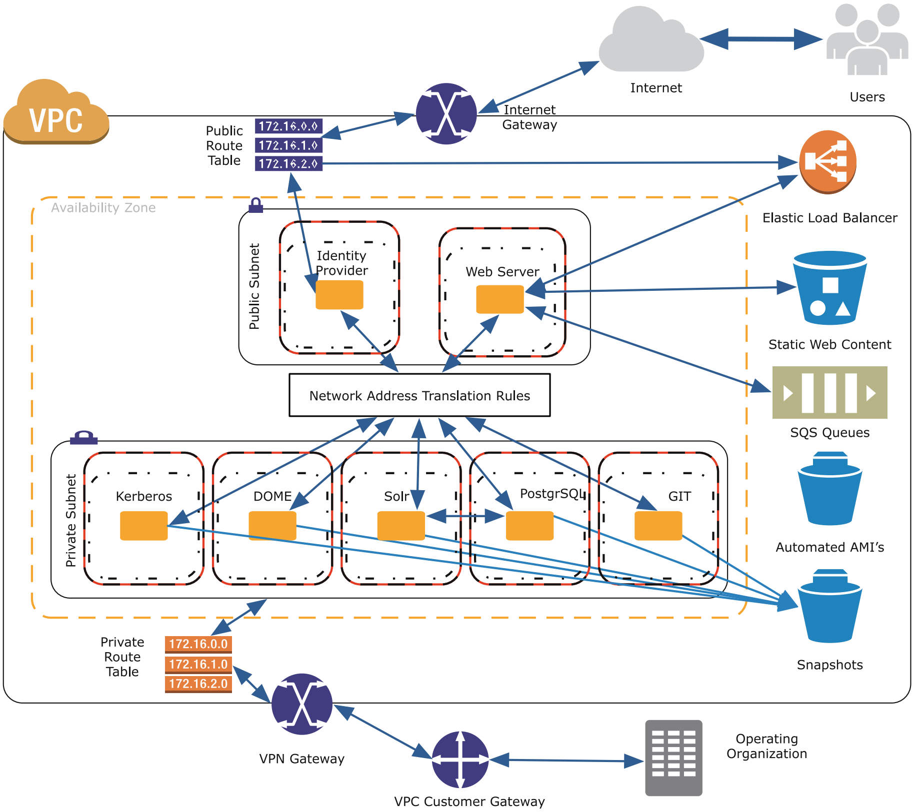


**Fig. 4.** Cloud deployment of the DMC

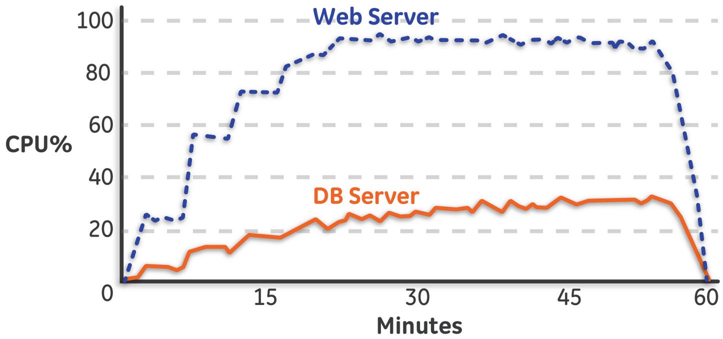


**Fig. 5.** Static system deployment

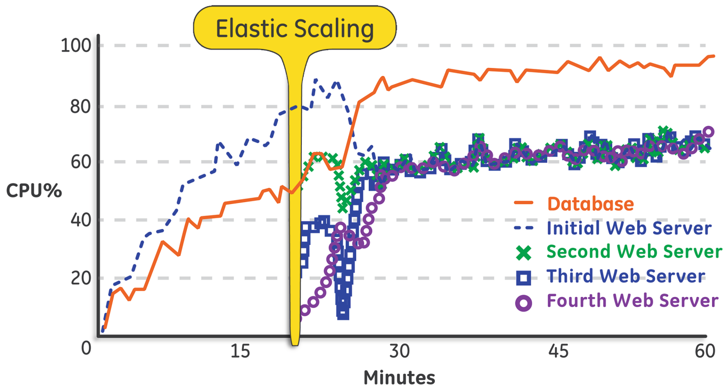


**Fig. 6.** Elastic system deployment

maximum number of instances in each auto scaling group to manage costs. In addition, scaling policies are assigned to each auto scaling group. These policies define when and how the scaling events occur.

Figures 5 and 6 show the results of load tests performed on a DMC deployment hosted in Amazon Web Services. Figure 5 shows the results of a load test performed on static deployment, using a single web server and database server, where all scaling events were disabled. In this experiment, increasing load was applied to the web server, as shown by the blue line. The load was generated using prerecorded site activity that was replayed using LoadRunner [18]. This experiment provides a baseline for the capacity of the web server and database server in a static environment. In comparison, Fig. 6 shows the results of a load test, using the same configuration, with web server scaling events enabled. Specifically, when a web server experiences a CPU utilization greater than 80 % for a five minute time window other web servers were created to manage the load. In Fig. 6, this scaling event is triggered and new web servers are created which lowers the CPU utilization of a web server from greater that 80 % to approximate 60 %.

## 4 Conclusions

The overarching benefit of the DMC is the creation of an industrial commons around digital manufacturing, where software-based manufacturing services can be exchanged, and where technology development is pulled by the market rather than pushed by vendors and technologists. Small and large manufacturers can work together, sharing models and expertise. With this form of industrial networking, productivity will increase, global economy will improve and new products will be created to better serve the Industrial Internet.

The DMC is currently used within GE. A team of engineers is working on enhancing the platform with the goal of having more than 100,000 users from companies, universities, research institutes, and entrepreneurs by 2017 [9]. We are now populating the marketplace with an initial set of representative design-manufacturing models. We are also working on improving the user interface (UI) and user experience (UX), and developing educational material for widespread dissemination. Rigorous security assessment and functionality testing are also being performed to ensure the platform's readiness for release to the user community.

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