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Digital Economy

Exploiting the Digital Economy for Product Realization in Manufacturing

by Paul Witherell and Soundar Kumara

Editor's Introduction

In this paper, we briefly discuss the evolving concepts of the digital economy, digital threads, and product realization (manufacturing) in the digital economy-enabled futuristic world. We posit that if we need to become self-sufficient, it is imperative that small and medium manufacturing enterprises need to be equitably integrated into the digital economy. We lead this discussion to the most important research questions related to representation, search, and composition to achieve such a realization.

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Almost a quarter century ago, Balakrishnan et al. addressed the vision of Big-M manufacturing wherein the authors considered a future of product realization in the context of digitization [1]. Two decades later we are trying to attempt to relate the future of manufacturing in the digital economy context. In exploring the broader impacts of digitalization, Tapscott is said to have coined the term, "digital economy," for the first time [2]. Though Tapscott did not define the term, he referenced it as the "Age of Networked Intelligence" where it is "not only about the networking of technology creating smart machines, but also about the networking of humans through technology" that "combine intelligence, knowledge, and creativity for breakthroughs in the creation of wealth and social development" [3]. Information technology has given us unprecedented connectivity which can be characterized by "reach (who is accessible)," and "range (type of information that is accessible)." Compared to 1999, today we have a wider persistent reach and range, signifying ubiquitous and multimodal information access. While the general population is able to enjoy widespread access to the digital economy, opportunities continue to exist to better integrate the underlying layers that drive our connectivity.

Digital Economy

The digital economy is characterized by traits such as no-exchange transactions (pure digital), on-demand, customization, personalization, variety' traceability, security, physical to virtual, NFTs (NIKE shoes), and virtual to physical. In the last five years, digital threads have become popular, which is a result of advances in both software and hardware. Improvements in high-performance computing, artificial intelligence (AI), machine learning, virtual reality (AR), and augmented reality (AR) have made digital threads a viable concept that can help in decision-making in every field. Today digital threads are becoming integral models for and of decision making. For the sake of clarity, we use the term, "digital economy," as an integrated system of hardware and software powered by the above-mentioned characteristics and driven by digital threads.

Digital Economy and Manufacturing

In this position paper, we will explore the digital economy in the context of manufacturing. We define digital economy in manufacturing as, "distributed manufacturing ecosystems that are ubiquitous, and persistent and powered by the unprecedented reach and range offered by advances in digital technologies, such as digital threads." We further define "equitable integration" [4] as a concept that implies that the marketplace (including manufacturing ecosystems) is not dominated or siloed by few, but instead integrated in a manner that all enterprises, large and small, are provided a platform on which business can be equally conducted with the consumer and with each other.

In the U.S. 71 percent of the 300,000 manufacturing enterprises are classified as small and medium manufacturers (SMMs) having less than 500 employees. They also contribute to 65 percent of the payroll in manufacturing. Therefore, it is imperative that any progress that needs to be made in the digital economy cannot leave SMMs behind. Exploring the ever-evolving dynamics between larger enterprises and SMMs, and what implications the digital economy is having and will have on how manufacturing does business in the future, is critical to take manufacturing beyond the current industry 4.0 paradigm.

The foremost premise of the digital economy is the ability to diminish physical barriers, especially distance, condensing time (the ability for instantaneous connectivity and ubiquity), and bringing entities (SMMs and larger companies) closer together. A digital presence allows manufacturers to interact more easily with each other and with the customer to create a stronger manufacturing economy. While digital presence indeed reduces barriers in manufacturing, such an arrangement does not mean uninhibited interactions. While the digital economy continues to offer equitable promise, the ability to realize many of the benefits is often relegated to larger enterprises. However, as concepts associated with the digital economy continue to mature, these benefits will be readily realized by smaller entities as well.

As the roles of SMMs continue to evolve, the digital economy is creating new opportunities across local and global economies. Many of these opportunities are created by SMMs to operate on larger platforms supported by the digital economy, allowing them to be more prevalent in larger manufacturing sectors. The ability of these SMMs to operate on these platforms, however, is very much determined by their ability to integrate. The digital economy is providing SMMs with growth opportunities like never before, but the ability to realize these opportunities is very much

determined by their ability to integrate with larger platforms, with larger manufacturers, and with each other.

Integration implies the ability of an entity or system to work, on some level, with a different entity or system. Various levels of integration can be achieved, and in general "better" integration of a sub-system means better integration of the overall system. Or, in the case of SMMs, the better equipped they are to work with and integrate with the larger digital economy, the better off they will be. To further explore this integration, we will investigate the role of three crucial factors in integration: representation, search, and composition.

Foundational Research Questions

Representation. Traditional representations are static, highly structured, fixed length, and historically built on relational databases. As online commerce evolves, more information is added to the data structure, and variable-length records have become the norm. As the digital economy evolves, the representation schema needs to offer the means for ubiquitous and persistent search and relate financial and third-party logistics providers and other service providers to be dynamically connected to the data structure.

Search. Imagine the context of a large manufacturer looking for a supplier to establish connectivity, select a supplier, and initiate all the other related services. Current search engines primarily locate the supplier and are not equipped with the capabilities to initiate continuous connectivity. In the digital economy, the search engine to connect SMMs should be able to accomplish the tasks not only related to connectivity but also to context-based service provisioning.

Composition. Today the manufacturer locates the supplier(s) through vendor selection analytics, draws up contracts, and initiates further tasks. It must be noted these are currently done in an offline fashion. In the digital economy-enabled world these tasks are expected to be initiated and completed in an interconnected manner. For example, given a large manufacturer's requirement a few SMMs may have to come together (form a coalition) to meet the demand and form stable partners in the future.

These three factors do not operate independently but rather require a deliberate approach to establish meaningful advancements. A new type of data structure is needed to accomplish representation, search, and composition seamlessly. We posit that the digital economy is not a simple manipulation of digital threads and establishing connectivity. To fully utilize the concept

and the resulting research and developmental issues, it is time for researchers to start asking important questions and circle back to the foundational data structures to fully integrate (loose integration) the product realization concepts with the digital economy. Establishing new paradigms on which the digital economy's "sublayers" operate is necessary to instill continuous, equitable integration between OEMs, SMEs, and their customer bases.

References

[1] Balakrishnan, A., Kumara, S., and Sundaresan, S. Manufacturing in the digital age: Exploiting it for product realization. *Frontiers of Information Science* 1 (1999), 25–50.

[2] Tapscott, D., The digital economy: promise and peril in the age of networked intelligence, New York: McGraw-Hill, 1996.

[3] Bukht, R. and Heeks, R. Defining, conceptualising and measuring the digital economy. *Development Informatics Working Paper* no. 68. August 3, 2017.

[4] Howse, R. Fragmentation and Utopia: Towards an equitable integration of finance, trade, and sustainable development. In Cassese, A. (Ed.), *Realizing Utopia: The Future of International Law.* Oxford University Press, 2012, 427-441.

Biographies

Dr. Paul Witherell is the associate program manager of the Measurement Science for Additive Manufacturing Program in the Engineering Lab at the National Institute of Standards and Technology and leads a project on Advanced Informatics and Artificial Intelligence for Additive Manufacturing (AM). Witherell is a mechanical engineer with an informatics and design background who has spent the past 10 years working in AM. His research efforts aim to leverage engineering and information sciences to benefit design flexibility, cost, and cycle times in AM. Witherell's current interests include artificial intelligence and machine learning for additive manufacturing decision support; modeling, simulation, and digital twins for additive manufacturing part qualification; and product definitions and data packages for additive manufacturing parts and supply chains. Witherell is a Fellow of ASME.

Dr. Soundar Kumara, Allen E. Pearce and Allen M. Pearce Professor of Industrial Engineering at Penn State, is a Fellow of IISE, ASME, CIRP, and AAAS. He received the David F. Baker Distinguished Research Award from IISE, the Excellence in Research Award from ASME Computers & Information Engineering (CIE) division, and is listed among the 20 most influential academics in smart manufacturing by the Society of Manufacturing Engineering. He has served as a chair, advisor, or co-advisor to 70 Ph.D. and 81 M.S. students. He has won the Penn State Engineering Alumni Society Outstanding Research, Premier Research, and Outstanding Advising Awards; the Penn State University Faculty Scholar medal; and the Graduate Faculty Teaching Award. Kumara is a recipient of the Distinguished Alumnus Award from the Indian Institute of Technology, Madras (2023), and was selected as the 2022 Outstanding Industrial Engineer from Purdue's School of Industrial Engineering. His research focuses on AI in manufacturing and healthcare, and complex systems analysis.

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