NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

DELTA

Whitepaper

September 2018

Delta-NTU Corporate Lab for Cyber-Physical Systems

Towards Manufacturing On Demand

The Delta-NTU Corporate Laboratory for Cyber-Physical Systems was jointly established by Nanyang Technological University (NTU) and Delta Electronics in June 2016, supported by National Research Foundation, Singapore. The Lab aims to create business value through collaborative commercialization of translational research and technology development.

Sponsors of Delta-NTU Corporate Lab

The National Research Foundation (NRF) Singapore, set up in January 2006, is a department within the Prime Minister's Office. The NRF sets the national direction for research and development by developing policies, plans and strategies for research, innovation and enterprise. The NRF aims to transform Singapore into a vibrant R&D hub that contributes towards a knowledge-intensive, innovative and entrepreneurial economy; and make Singapore a magnet for excellence in science and innovation.

Established in 1981, the School of Electrical and Electronic Engineering is one of the founding Schools of the Nanyang Technological University. It is one of the largest EEE schools in the world, with more than 150 faculty members and an enrollment of more than 4,000, including about 1,000 graduate students, built on a culture of excellence and renowned for its high academic standards and research, the School ranks 6th in the field of Electrical & Electronic Engineering in the 2017 QS World University Rankings by Subjects.

Delta Electronics was founded in 1971 and is a global leader in power electronics, energy management and solutions for smart green life. Committed to its mission "to provide innovative, clean and energy-efficient solutions for a better tomorrow" and supported by 70 R&D sites and more than 9,000 R&D engineers globally, Delta is a frequent recipient of international awards and related recognition for innovation, design, and corporate social responsibility.

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Prelude

The unprecedented convergence of changes in economic structure, international politics, consumer demand and IoT technology in the past decade has ushered in a new era in manufacturing. Delta-NTU Corporate Lab foresees a paradigm shift and envisions potential opportunities to shape a new industry by catalyzing the changes in manufacturing. Since its inception, Delta-NTU Corporate Lab has been ramping up its research capacity in smart manufacturing by tapping into knowledge of Delta Research Center (DRC) and NTU as well as resources of NRF and the ecosystem. Singapore's position as the innovation and entrepreneurship hub in Southeast Asia has allowed the Lab to keep abreast of what is happening in advanced manufacturing technologies. In this whitepaper the Lab explains what opportunities the paradigm shift will create and how the Lab can help to unleash the potential of small and mid-sized manufacturers in the changing landscape.

Paradigm Shift

The Age of the Customer

The prevalence of mobile devices and social platforms, by enabling consumers to express personal identity and share their points of view, has fueled the consumers' demand for personalization. On the other hand, these technologies allow marketers or manufacturers to understand the needs of individual consumers and provide tailored products. The Forrester report published in 2013 aptly described this trend as "Technology Management in The Age of The Customer," predicting the age of the customer would place harsh and unfamiliar demands on institutions. In the past five years, we have seen such phenomenon manifested in many consumer and household product sectors, ranging from sports shoes to automobiles. Coupled with the changes in sales channels and marketing approaches, the information technologies have changed the way products are designed, manufactured and marketed. Consumers are no longer satisfied with the standardized products available through retail stores. Manufacturers have been trying to fulfil the demand for personalization and immediacy.

The Backlash Against Globalization

In the past decades, globalization has redistributed jobs[1], wealth[2] and resources between developed countries and countries with lower wages. Thanks to free trade, export economies have long dominated in East Asia with most U.S. and European companies concentrating their manufacturing in this region. Subsequently, the rising protectionism in the Western economies started to change the global manufacturing landscape. As the trade war intensifies and sends tremors down the global supply chain, many companies are evaluating their customer footprints. To confront the economic and political uncertainties, they have to rethink their supply-chain strategies for long-term competitiveness.

The Consciousness of Sustainable Consumption and Production

The accumulating evidence that the global economic growth was attained at the expense of the natural environment, energy reserves, and living standard in the developing countries has aroused the awareness of sustainable consumption and production. Global consumers increasingly resonate with the idea that, if unrestricted, the way we produce and consume goods will have a grave impact on air quality, water and food safety, and social conditions for those underprivileged residents around the factories as well as factory workers.

As a result, policymakers in the developing economies have been steering a transition to a more balanced and greener growth path. For example, the authorities in some countries have ramped up their programs of environmental inspections. Power plants were shut down and steel mills curtailed their operations to reduce air pollutant emissions. To achieve sustainable growth, more stringent policy enforcement will continue to exert pressure on low-value, high-pollution manufacturers and reshape the structure of the manufacturing sector in developing economies.

Unprecedented Disruptive Power of Technology

Pervasive digitization, ubiquitous connectivity, and improved computing power have the potential to disrupt many aspects of manufacturing. For the first time in history, networked machines can respond to changing demand in real time. With the advances in artificial intelligence, it is no longer a fanciful scenario that a production line can act autonomously based on self-learning. From Manufacturing USA, Made in China 2025, to Germany's Industrie 4.0—the global economic powerhouses are racing to secure their leading positions in manufacturing by staying at the forefront of these technologies. Along with this paradigm shift in manufacturing come both opportunities and threats. Manufacturers of all sizes have to be aware of the profound implications these technologies have on their business.

Manufacturing on Demand (MOD)

Deterred by the escalating labor costs in the past decade, some US and European companies have gradually moved their production out of developing countries. Now the trade war makes this trend appear more irreversible. Although some manufacturers opt for destinations with a view to remaining low-cost providers for their labor-intensive productions, others intend to stay in close proximity to their customers—from the perspectives of both geography and economic structure[3]. The shift from offshoring to nearshoring, which contributes to a phenomenon known as manufacturing regionalization, requires the manufacturers and their suppliers to develop capabilities other than the endless pursuit of cost efficiency so that the increased responsiveness to the market demand and reduced transportation cost can compensate for the disadvantage in labor cost.

Many of the manufacturing facilities we see today are optimized for high-volume, low-mix productions. Many are characterized by “build to stock” systems where raw materials are procured in advance based on historical patterns, and large quantities of products are manufactured in prescheduled shifts. It is also not unusual that some manufacturers who specialize in certain products can keep their status quo, supplying the same products stably and profitably in a decades-long relationship with their customers. However, it is getting more difficult for such manufacturing systems to cope with changing customer expectations nowadays. The closer proximity to industrial customers and growing consumer demand for customization call for more agility and flexibility in production.

Although some manufacturers still continue to run state-of-the-art facilities for mass production, we envision a world where more factories capable of high-mix, low-volume production will rise up to the challenge of customer-driven manufacturing, especially discrete manufacturing. Empowered by the

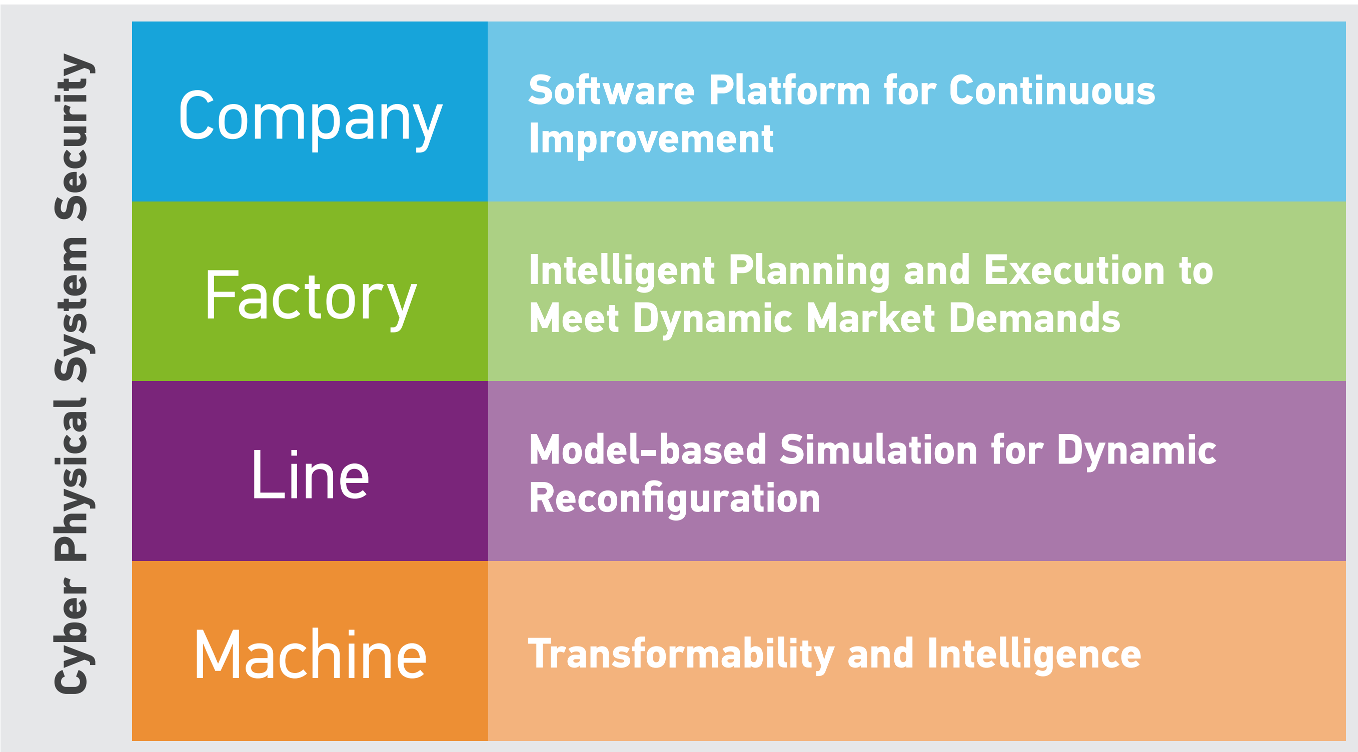

Figure 1: Competencies Required for Manufacturing on Demand

technologies for advanced manufacturing, a new breed of factories no longer competing on scale and cheap labor will thrive in this new era by embracing an approach known as Manufacturing on Demand (MOD).

Described as a vision for smart manufacturing by some or associated with 3D printing by others, Manufacturing on Demand is not a new term we coined. However, we would like to offer an actionable proposal to make MOD attainable. Backed by a thorough analysis of the current pain points and the identification of major trends in manufacturing, our vision took shape following two years of networking with advanced factories in China, Japan, Singapore, and Germany. We have also gained insight from research institutes, policy makers as well as exhibitors and visitors in major tradeshows. Herein we present a blueprint for technology enablement to catalyze MOD from a forward-looking perspective.

To explain the MOD concept in a systematic approach, we will highlight the pivotal technology areas from the company level down to the machine level. The ultimate goal is for a manufacturer to translate these technologies into long-lasting competencies for each layer (Figure 1).

Company

MOD is aimed to continuously evolve and respond to changes. Knowledge can be accumulated and extracted during the evolving process—anywhere from understanding new customer requirements and developing a new production technique to tailoring an algorithm to the customer's new products. This knowledge base will accelerate a manufacturer's new product design and engineering process.

However, to harness and reuse such knowledge entails a robust software platform. For enterprises and SMEs alike, the affordability of a software-based solution lies not only in the cost charged by the vendor for design, development, testing, and deployment but also in the risk that they are at the mercy of an inflexible architecture when the software needs maintenance or change at a later stage in its life cycle. In fact, the way a software platform is architected determines whether it can be changed and customized easily and cost-effectively. A flexible architecture not only cuts costs in maintenance and reuse but also reduces resources in computation.

Consequently, a software platform that can support continuous improvement and adapt to changes dynamically is the cornerstone for a company to realize MOD.

Factory

Digitization is the prerequisite for MOD. It is only when data can be collected, transmitted, and analyzed digitally that a manufacturing process can respond to customers' demand in an agile and flexible way. The level of digitization varies depending on the application. Digitization is an iterative process because applications are added or changed from time to time. It is important that the tools for digitization can accommodate different applications and allow for seamless and cost-effective system integration.

Once we attain visibility into the data and their relationship from end to end in the entire system, we are able to instil intelligence into a factory. By aggregating and integrating a vast array of data, a knowledge-based system can provide actionable insights on how to boost productivity and reduce costs. An MOD-capable factory develops intelligence that can support decision making at various phases to optimize planning and execution.

Line

The foundation of MOD is a flexible and reconfigurable manufacturing process that requires interchangeable and mix-and-match design among machines, workers and tools. In this way, a factory can reconfigure and reuse the assets it owns or can lease equipment to quickly respond to the changing demand.

Application-driven digital twin models representing the physical entity can be designed. To fulfil an order with the MOD approach, the most suitable manufacturing units are modeled, simulated virtually before physical configuration. Generic data models that systematically capture the physical and computational behavior of machines in a production line are required for such simulation. The selection of these suitable units should be fast and optimized through a system where the decisions can be based on the status of resources within the factory, including process capability of machines, product types, layout and capacity of the production lines, material status of the manufacturing unit, intralogistics and automation processes.

Machine

As the demand for customer-specific solutions grows, product variants proliferate and product life cycles become shorter. While many manufacturers don't want to miss out on the high-mix, low-volume orders, they also consider it imperative to maximize the utilization of their production equipment. They grapple with such challenges as how to make a machine versatile enough to outlive a multitude of product variants and how to revive a machine by adding advanced functions when new customer demand arises. We believe a transformable machine can tackle these challenges.

In addition, intelligent planning and execution at the factory starts from intelligent machines. Intelligent machines autonomously operate in a mode that best suits the current product. These machines are able to act with minimal human intervention and complete a task based on their own intelligence. To achieve such intelligence, AI capability is required in semantic scene understanding, including detection, localization, identification and classification, so that machines have the ability to see, to think, to learn, and to make decisions. In addition, a learning framework that allows remote services to be performed conveniently is required in order to lower the cost during the updating and upgrading of the machine intelligence.

Cyber Physical System Security

Cyberattack threat vectors grow rapidly in the age of connected machines, production lines, factories, and supply chain. The ubiquitous information flow and connectivity in the production exposes vulnerabilities from the machine level all the way up to the company level. Unscheduled and exceptional events are inevitable no matter how rigorous the security standards those manufacturing systems are designed to comply with.

New measures in cyber security need to be implemented to strengthen the resilience of the production system and ensure business continuity so that anomalous activities can be detected in time, unauthorized access to proprietary data can be prevented, and critical systems can be recovered rapidly from attacks.

Meanwhile, as we expect the increasing prevalence of man-machine collaboration using autonomous robots like robotics manipulators and automated guided vehicles, we have to rethink how to strike a balance between safety and mobility to ensure protection of assets and workers during the manufacturing process.

Safeguarding both cyber and physical aspects of the manufacturing environment is thus integral to the competencies required for MOD.

Together with the ecosystem, we work on the Cyber-Physical System (CPS) technologies to enable a new breed of manufacturing. Our goal is to shape a new industry by catalyzing the transformation into MOD.

Empowered by the technologies for advanced manufacturing, a new breed of factories no longer competing on scale and cheap labor will thrive in this new era by embracing an approach known as Manufacturing on Demand (MOD).

Catalyzing Manufacturing On Demand

Lifetime Service Support

We aim to realize our vision by starting a service that supports a manufacturer's needs at different stages of transforming its facilities into MOD-capable factories, which we dub "lifetime service." This service comprises three pillars in our current roadmap:

Solution Development and Delivery

We will build a customer engagement platform where a manufacturer can interact with our project teams in its individual secure online space. The manufacturer can stay updated on the solution development progress and provide feedback timely.

To enable solution development and delivery, the customer engagement and solution development process should be efficiently managed in a process in which cross-functional members on a project team can collaborate seamlessly. Underpinning such process is a knowledge management platform that can harness the collective wisdom and best practices and can allow a solution to continuously evolve. This will only provide agility in addressing a customer's changes in requirements but also accelerate the replication or customization of the solution for other customers.

Remote Services

We will be able to provide remote services, which range from optimization of parameters to retraining of a model. Apart from minimizing the time and cost for traveling, providing an alternative for on-site services can have our engineers better utilized for high value-added tasks.

To enable remote services, it is essential to develop competencies in data analytics, which will allow us to identify the best setting or model for a customer's scenario based on valid data on the customer's side as well as our own knowledge base. No less critical to the success of remote services is a secure and reliable online access to and storage of the customer's data that the customer can trust.

Smart Learning

To build the competencies for MOD, it is essential for manufacturers to find and maintain good talent. Utilizing a versatile learning platform to close the skill gap will increase the effectiveness of learning, complement the tutor-led training in a physical classroom, and reduce cost, especially in an industry troubled by a high turnover rate of direct labor. A manufacturer can conduct trainings and disseminate tutorials—be it quality management or engineering maintenance, to upskill its workforce.

To enable smart learning, we need to build a set of tools to help a manufacturer design training programs, create content and share knowledge. We should also allow each user to personalize his or her learning with AI and get the most relevant content.

Building Blocks

Underlying this lifetime service support are two building blocks: Transformable Intelligent Machines and IoT software platform and solutions.

Transformable Intelligent Machines

Compared with mega-factories, small and medium-sized manufacturers are more constrained in their resources and capital expenditure. It is not justifiable for them to invest in machines designed only for producing a limited number of product models. Nonetheless, the large producers are also seeking solutions to maximize their utilization of their equipment, especially for high-mix, low-volume productions. We expect the emergence of transformable intelligent machines (TIMs) will maximize utilization and extend the life span of machines.

Composed of physically compatible elements, a TIM balances standardization and modularization. The transformability of TIMs lies in the design that decouples dependencies of functions and shares standardized modules and interface. To transform the function of a

Lifetime Service Support

Collaboration with the Ecosystem

Building Blocks

machine, one can swap out the major components or modules. Alternatively, the function can be redefined or reconfigured by software. In the longer term, the ability to have machines designed with software-defined functions will further increase the utilization rate of machines.

On the other hand, the intelligence of TIMs hinges on the machine's ability to learn from vast quantities of data and act autonomously in different scenarios. This reduces the need for manual activities in production processes. Delivering such intelligence takes a blend of competencies in software development and analytics.

The TIM initiative is at a nascent stage. However, we have been researching and developing related technologies in the past two years, including the following:

- A universal Simultaneous Localization and Mapping (SLAM) based navigation kit that can empower ordinary automated guided vehicles (AGVs) with a smarter navigation function
- A universal ultra-fast and precise 2D/3D imaging system for assembly processes
- A highly configurable laser emitting module that provides high-quality individual heating control
- A learning based optical defect inspection that identifies defects with high accuracy and flexibility
- A simulation software for autonomous mobile robot management in the factory

IoT Software Platform and Solutions

We are developing software solutions based on an IoT software platform built by Delta Research Center. The platform, unlike other software characterized by heavy footprint and entangled design, is architected to enable parallel development. With different components modularized and well defined in their degree of decoupling, the platform makes it easy to customize a solution and to adapt to changing requirements by reusing software components known as minimal essential units, thereby addressing the aforementioned issue of affordability. As a result, solution development cycles can be shortened while the platform is evolvable in the long term.

Meanwhile, standardized interface is being developed to address compatibility issue with other software.

Collaboration with the Ecosystem

Shaping a new industry to catalyze MOD calls for an ecosystem of players that can augment the offerings on each platform. We will share our roadmap with partners and invite them to grow their business based on a new model.

For example, to jumpstart the TIM initiative, Delta Electronics can take the lead in designing and manufacturing the hardware for a universal kit, be it for navigation or 3D imaging, while system integrators are encouraged to develop software that can tailor the functions of these devices to their respective customers' use cases.

Delta Electronics can also work with machine builders to design machines based on the principle of modular standardization, allowing machines to share standardized modules or sub-systems but fulfil different needs by plugging in add-ons that specialize in different functions. While Delta Electronics can produce the standardized modules or sub-systems, all machine builders can develop the add-ons for their domains and maximize the choices for their customers.

For our IoT software platform to gather momentum, Delta Electronics will first build reusable software components for industrial and building automation and open up the platform to third parties. Software developers can expand the scope of applications to various domains and gain access to more users they alone cannot reach.

We will also partner with consulting companies, system integrators, and industrial park operators as a new avenue to reach prospective customers.

We believe only by sharing with our partners the value co-created from the platform economy will we accelerate the realization of our vision.

Acknowledgement

Delta-NTU Corporate Lab would like to express our sincere gratitude to the following parties (listed in alphabetical order) for their insight and support that contributed to the development of our vision and technologies:

- Agency for Science, Technology And Research (A*STAR) Singapore
- Ascendas-Singbridge Group
- Bosch Group
- China Center for Information Industry Development (CCID) Group
- Delta Group
- Enterprise Singapore
- Festo AG & Co
- IBM Research
- Nanyang Technological University
- National Research Foundation Singapore
- NEC Corporation
- Peking University
- Prime Minister's Office of Singapore
- Singapore Economic Development Board
- Yokogawa Electric Corporation

Notes and Sources

1. The United States lost 3.2 million manufacturing jobs between 2001 and 2013.

   Source: Robert E. Scott and Will Kimball, "China Trade, Outsourcing and Jobs," Economic Policy Institute, December 2014

2. The above report indicated that in 2011, rising trade with less-developed countries reduced wages by 5.5 percent, or $1,800, for full-time workers without a four-year college degree.

3. In a whitepaper published by the World Economic Forum, manufacturing regionalization was identified among the drivers of the future of manufacturing.

   Source: Manufacturing Our Future-Cases on the Future of Manufacturing, World Economic Forum, May 2016

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