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The Industry 4.0 revolution and the future of Manufacturing Execution Systems (MES)

Francisco Almada-Lobo

Critical Manufacturing
almada.lobo@criticalmanufacturing.com

Letter from Industry

Industry 4.0 dictates the end of traditional centralized applications for production control. Its vision of ecosystems of smart factories with intelligent and autonomous shop-floor entities is inherently decentralized. Responding to customer demands for tailored products, these plants fueled by technology enablers such as 3D printing, Internet of Things, Cloud computing, Mobile Devices and Big Data, among others create a totally new environment. The manufacturing systems of the future, including manufacturing execution systems (MES) will have to be built to support this paradigm shift.

Keywords. Industry 4.0, Cyber-Physical Systems, Manufacturing Execution Systems.

1 Introduction

Since the final report of the Industry 4.0 Working Group[1] was published in April 2013, both academia and industry professionals have been trying to fully comprehend the consequences for manufacturing. Of particular interest are the consequences for manufacturing IT systems.

That Industry 4.0 document aimed to define Germany's investments in research and development related to manufacturing for the upcoming years. The main objective was leveraging the country's dominance in machinery and automotive manufacturing in order to position it as a leader in this new type of industrialization.

Industry 4.0 is based on a concept that is as striking as it is fascinating: Cyber-Physical Systems (a fusion of the physical and the virtual worlds) CPS, the Internet of Things and the Internet of Services, will collectively have a disruptive impact on every aspect of manufacturing companies. The 4th industrial revolution, which unlike all others, is

[1] "Recommendations for implementing the strategic initiative INDUSTRIE 4.0",
Final report of the Industrie 4.0 Working Group,
http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf

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being predicted, therefore allowing companies to take specific actions before it happens.

Manufacturers can begin now to define their target manufacturing model and then plan a transformation roadmap. Despite the significant hype around the topic, nobody knows what the exact consequences are for manufacturing operations or when will these happen, although there's a clear notion that the later-movers will most likely be forced out of the market.

While there's still a lot of confusion about the implications for manufacturing, the confusion starts with what matters in Industry 4.0. Considering the technology enablers for Industry 4.0. Include Mobile, Cloud, Big Data analytics, Machine to Machine (M2M), 3D Printing, Robotics and so on there are many companies with particular expertise. While these are in fact the disruptive technologies triggering the transformation, this Industry 4.0 revolution goes far beyond these.

2 Cyber-physical Systems

Cyber-physical Systems (CPS) are simply physical objects with embedded software and computing power. In Industry 4.0, more manufactured products will be smart products, CPS. Based on connectivity and computing power, the main idea behind smart products is that they will incorporate self-management capabilities.

On the other hand, manufacturing equipment will turn into CPPS, Cyber-Physical Production Systems - software enhanced machinery, also with their own computing power, leveraging a wide range of embedded sensors and actuators, beyond connectivity and computing power. CPPS know their state, their capacity and their different configuration options and will be able to take decisions autonomously.

As mass production gives way to mass customization, each product, at the end of the supply chain, has unique characteristics defined by the end customer. The supply chains of Industry 4.0 are highly transparent and integrated. The physical flows will be continuously mapped on digital platforms. This will make each individual service provided by each CPPS available to accomplish the needed activities to create each tailored product.

While the challenges at the supply chain level are quite big, the challenges at the factory level are not smaller. The combination of CPS and CPPS is likely to trigger significant changes in manufacturing production and control, towards completely decentralized systems.

Industry 4.0 advocates that the shop-floor will become a marketplace of capacity (supply) represented by the CPPS and production needs (demand) represented by the CPS. Hence, the manufacturing environment will organize itself based on a multi-agent like system. This decentralized system with competing targets and contradicting constraints will generate a holistically optimized system, ensuring only efficient operations will be conducted.

3 Reaction of MES providers

The direct consequence for centralized systems is that they will simply cease to exist. For Manufacturing Execution System providers, this will become a quite challenging scenario. Within the MES suppliers group, reactions to this upcoming disruptive future vary.

A first group, representing the big majority is simply ignoring Industry 4.0 and doing business as usual.

A second group is paying more attention to it. However, they claim Industry 4.0 defines a target model which will most likely take years or decades to reach. In the meantime, they say, companies should still try to continue investing in centralized MES systems and keep improving the performance of their operations. It is actually true that many industries are still in the dark ages of efficiency and quality and they should really evolve step by step, implement MES systems and related operations management practices, before dreaming about cyber-physical systems networking autonomously.

A third group however, argues that the decentralized systems will always need a centralized system due to compliance, optimization and monitoring. This is quite contradictory and frankly, these providers are truly missing the point. The shop-floor becoming a marketplace of capacity and production needs, where smart materials and smart equipment negotiate autonomously, guaranteeing the best possible efficiency contradicts the model of centralized system control. Where compliance is concerned, the solution proposed by Industry 4.0 lies in the vertical integration of smart materials and equipment with compliance-oriented business processes, while data reporting and analytics of such distributed systems is resolved by data lakes and big data.

4 Manufacturing Execution Systems of the Future

Manufacturing Execution Systems have been pivotal in the performance, quality and agility needed for the challenges created by globalized manufacturing business and will most likely continue to be. However, a completely new generation is required to cope with the new challenges created by Industry 4.0. The following are the four main pillars these systems shall consider.

4.1 Decentralization

One fundamental aspect which needs to be clarified is the notion of decentralization. This decentralization does need to be physical, but instead a logical one. What this means is that a smart product or CPS, as long as it has the capability to identify itself and connect to a physically centralized system, providing its position and state, the computing power can be elsewhere. In fact, with cloud computing, it's even arguable if such as system can be considered physically centralized. But the logical decentralization must still exist.

So the MES is still one application, but it acts decentralized with agents/objects representing the shop-floor entities. As an example, a smart product knows its state, its position, its history, its target product and its flow alternatives. Likewise, a piece of smart equipment, or more broadly a smart resource or CPPS will know its state, its history, its maintenance plan, its capacity, its range of possible configurations and setups, etc.

Smart materials and smart resources are not coupled entities. A dispatching operation shall represent the logical binding between a material to be processed and a resource to process the material. The first is a service consumer and the second a service provider.

Additionally, context resolution possibilities shall allow each product to be unique. When a product requires a certain service at a certain step, but adapted, or unique to its specific context, it shall differ from a combination of the flow with a target product type or specific product category.

Going one step further, the smart product may hold the recipe needed at a given processing step. When negotiating with the smart resource, it will transfer the recipe to the resource so that it can perform its unique transformation process.

4.2 Vertical Integration

Beyond the already referenced supply chain transparency, achieved through horizontal integration across the supply chain, the compliance, control or the fulfillment of any other related corporate business process is guaranteed through the vertical integration.

All services which the different CPS and CPPS entities can provide are exposed, allowing their orchestration in business processes that may be simple or complex for compliance or more broadly related to quality, logistics, engineering or operations. The MES must then be truly modular and interoperable, logically decentralized, so that all functions or services can be consumed by smart materials, smart equipment or any other shop-floor entity. As an example, a typical maintenance management process, often centralized, in this approach shall consist of a series of services that each piece of equipment might use.

4.3 Connectivity and mobile

Connectivity within the shop-floor can hardly be considered something new. What is changing now is how easy it is to achieve such connectivity, with significant impact in the overall manufacturing operations.

Advanced manufacturing environments have had such connectivity for a long time. As an example, some of the more sophisticated semiconductor facilities have RFID or transponders in the material containers and the equipment has bidirectional communication through interfaces, exposing readings from sensors, alarms or reports or allowing recipes to be externally selected or downloaded.

Now, industry 4.0 is creating a true democratization of such connectivity, allowing it to be widespread in manufacturing facilities of different sophistication levels.

- On one side, passive identification tags are increasingly affordable; these allow all shop-floor entities to hold their positioning coordinates. The logically autonomous MES entities can which store this location data and show it in real-time in interactive maps.
- On the other side, the IoT, in the industrial world called IIOT (Industrial Internet of Things), translates into very low cost hardware and lean OS (such as

Windows 10 IoT running on a Raspberry Pi), allowing true connectivity with equipment not requiring heavy systems and interfaces.

On the more operational MES front, connectivity and mobile combined shall allow more adaptable interfaces. MES will consist of different "apps", making the vision of getting to a piece of equipment, downloading and later using an app specifically built to operate that equipment will become a reality.

The same combination of mobile devices with the increase in reliable and inexpensive positioning systems will also allow the representation of real time positioning in 3D maps, opening the door to augmented reality scenarios. These are expected to bring tangible gains in areas such as identification and localization of materials or containers or in maintenance related activities.

4.4 Cloud computing and Advanced Analysis

Cloud computing and advanced analytics constitute the fourth pillar of the MES of the future. Both CPS and CPPS will generate huge amounts of data, which needs to be stored and processed. The Smart Factory vision of Industry 4.0 requires achieving a holistic view of manufacturing operations. Clearly this can only happen by integrating data from several different sources.

Advanced analytics are then needed to fully understand the performance of the manufacturing processes, quality of products and supply chain optimization. Analytics will also help through identifying inefficiencies based on historical data and allowing corrective or preventive actions to be performed.

The analyses are of two types.

- First, these can be offline analysis using very sophisticated statistical process models. These will need to be both in structured data, generally residing in a relational database or in data warehouse cubes, and in unstructured data, which is very difficult to analyze with traditional tools.
- Second, some actions must be triggered as quickly as possible, even before data is stored. This needs real-time analysis of data using techniques such as "in-memory" and complex event processing.

5 Conclusions

The very prediction of Industry 4.0 has created unique opportunities for defining target roadmaps for manufacturing operations in general and for manufacturing IT systems in particular. Centralized and monolithic production monitoring and control applications will eventually cease to exist, giving way to solutions capable of supporting this radically different vision of connected yet decentralized production and supply chain processes.

The decentralization of computing power does not need to be physical, but rather logical, allowing autonomous decisions in a market-like manufacturing environment composed by service providers and service consumers within the shop-floor, vertically and horizontally integrated for aligning with manufacturing business processes and the overall supply chain.

Solutions using these principles already exist today and are the ones which shall support manufacturers in creating their manufacturing wide picture and roadmap, with step by step actions, leading to the ultimate vision of Industry 4.0. As manufacturers build their Industry 4.0 roadmaps, it is critical that they understand these core principles so they are not faced with difficult replacement decisions.