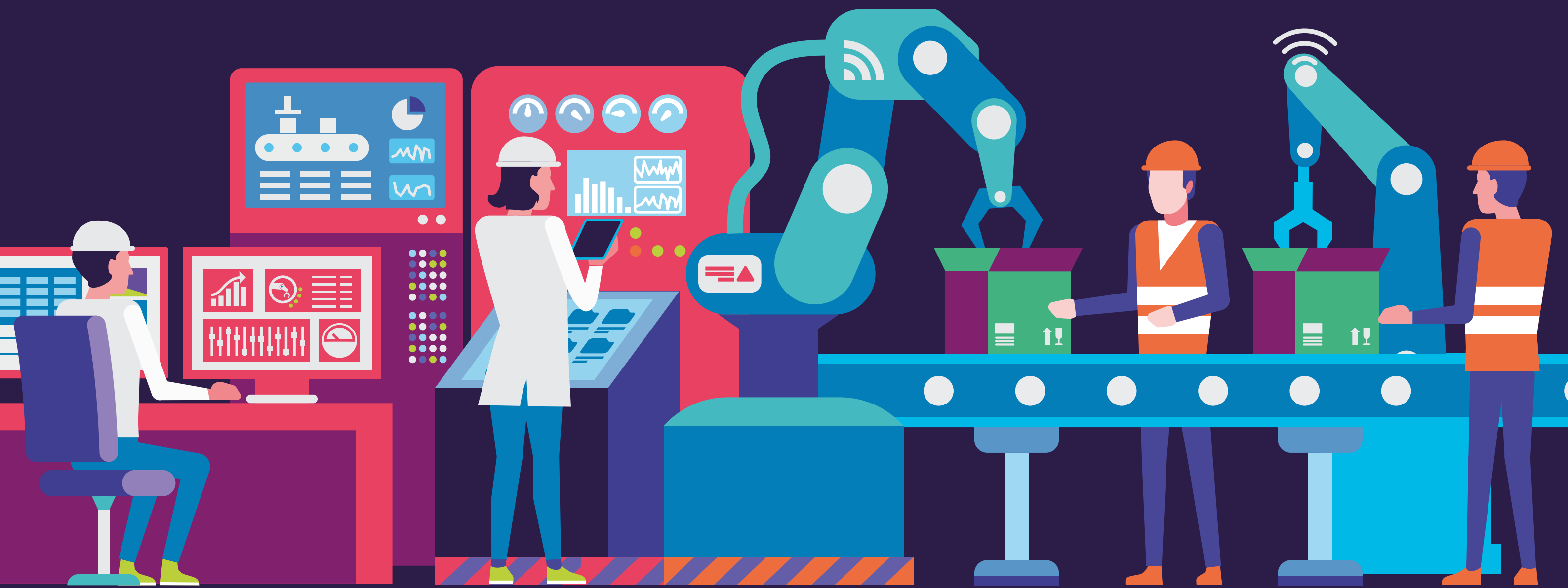
Smart Manufacturing Operations Management

Orchestrating Factory 4.0



Introduction

Today, a digital revolution is underway that is significantly transforming our economy and societies. The extent of the impact is difficult to anticipate as there are endless possibilities for applying digital technologies. At the same time, if we take a closer look, digitalization comprises the convergence of three phenomena that together offer new capabilities with tremendous applications.

Ever-growing data and ease of data availability and sharing

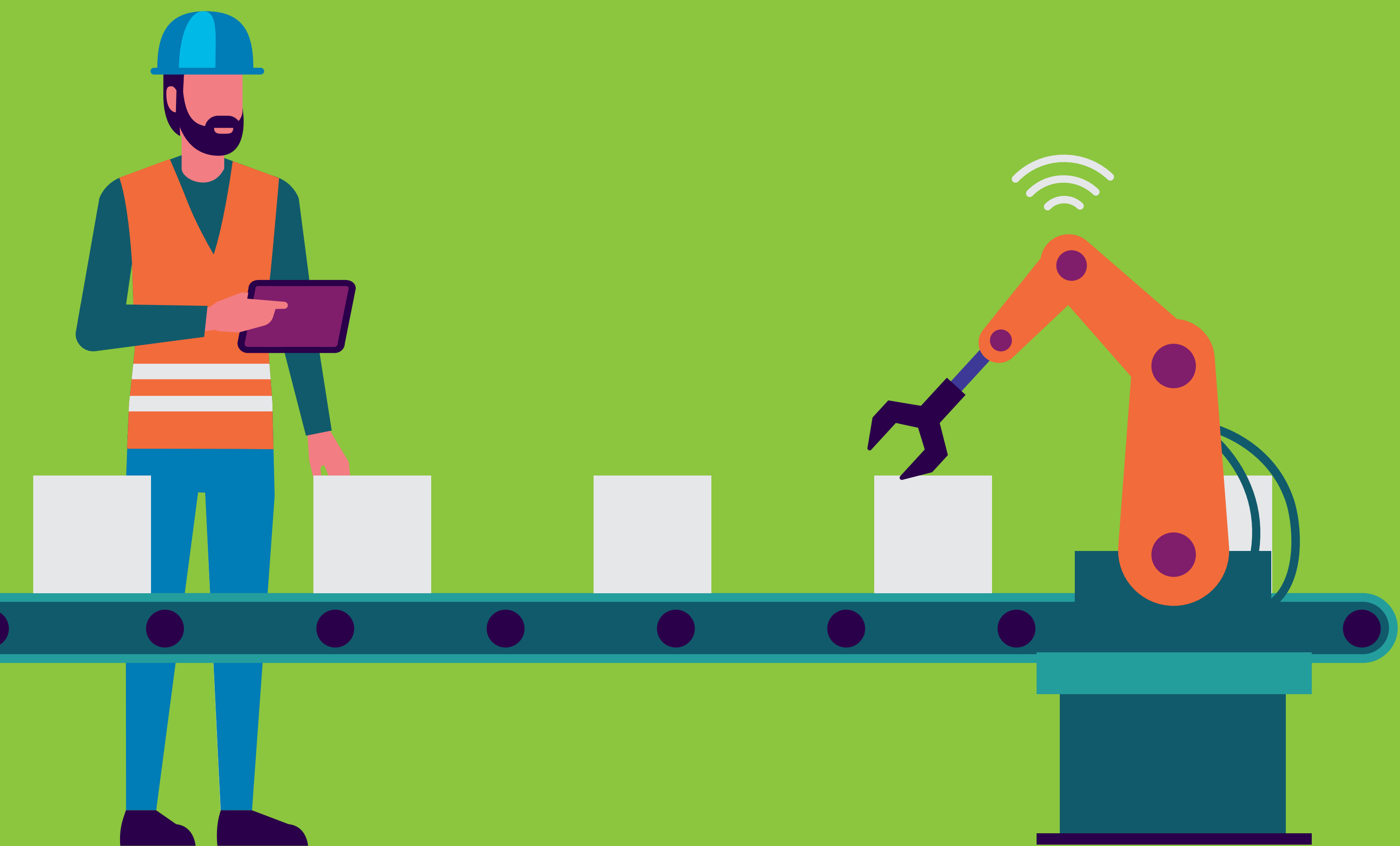
The increasing use of the internet, smartphones, tablets, and connected objects across sectors and industries is growing the volume of data generated every second. Moreover, the data is easily accessible in near-real time, owing to a multi-connected and cloud world.

Ultra-powerful computing power

Computing power is growing exponentially. We have already reached a stage where ERP software designers prefer to compute the same calculation a thousand times in a fraction of second rather than physically storing the results of previous calculations in a specific database, whose access would be slower.

Increasing adoption of advanced algorithms

Advanced computational capabilities combined with improved availability of large volume of data have led to an increasing use of predictive, optimization and learning algorithms, usually grouped under artificial intelligence capabilities. The combination of such algorithms has found several applications, including industrial performance improvement, prediction of scenarios, virtual reality, autonomous cars, and natural language processing.



Digital to empower the industry of future

Digital technologies and related science have led to the rise of Industry 4.0 or the Fourth Industrial Revolution. After steam, electricity, and automation, it is now digital technologies and connectivity that drive the new paradigm shift to address the economic challenges of the twenty-first century.

Everyone and everything is connected and producing data all the time

Managers, supervisors, quality controllers, logistics, production and maintenance operators—everyone is connected and mobile via tablet, smartphone, barcode reader, or even hardened or embedded computer station. Irrespective of their location or environment, they are connected to an internet-like network and receive and transmit data in real time.

Moreover, devices and machines are also connected, including mobile tools (screwdrivers, etc.), pallets, containers, mobile trolleys, production machines, robots, cells, and even an entire fully automated and autonomous assembly line (thus considered as a simple connected object). The connections are either native for recent installations, made through existing applications already connected to the production environment (MES, SCADA, HISTORIAN, etc.), or delivered using additional sensors. Indeed, it is now very simple to put all kinds of sensors (Industrial IoT)—simple or sophisticated—on machines, containers, or existing infrastructure. However, it is more difficult when it comes to driving machines and production flows. In such cases connection via specialized applications such as LES, MES, or SCADA is often unavoidable.

People, machine, and infrastructures are thus originators of data that can be used in near-real time and stored in shared spaces.

Let us pause to consider the expression "near-real time". Synchronizing real-time logistics and production operations is an essential part of Industry 4.0. It has to be well understood that we do not mention systems response time in milliseconds as one may for control systems and servo loops specific to production equipments. The expression "near-real time" in our context refers to a response time between a second and few minutes. For this paper, "real time" should be read as "near-real time."

A world of demanding technophiles

In an increasingly technology-driven and competitive world, consumers fail to come to terms with the fact that their needs or demands can't always be met or delivered satisfactorily. They find it difficult to conceive of delays, errors in delivery, or defects in products, or to understand that the product of their dreams has not yet been developed. They are unhappy if they can't change the color, size, or configuration as they seem fit or if they can't change their minds at the last moment. They can't imagine not having the information on the progress of their order in real time. At the same time, they seek product quality and security of the highest order and with continuous enhancements.

In this world of technophiles, consumers no longer ask whether their demands can be met; they question why such flexibilities don't already exist. They have similar expectations at their workplace and while interacting with a supplier, partner, colleague, or another department. They expect their work environment and tools to offer similar functionalities and services as those commonly offered by mass market providers.

Therefore, such needs across the value chain of manufactured products, whatever the sector, are perfectly aligned with the new habits of consumption and collaboration at work that include:

- Immediate availability of increasingly personalized and diversified products
- Products consumed as services—on-demand and on-the-move in all places
- Ever higher quality standards and ever more demanding industry regulations.

Orchestrating Factory 4.0 with Smart MOM

In this context, Capgemini has gathered the requirements of Industry 4.0 plant management tools that help you meet such needs. We outline the concept of Smart MOM wherein the standard functions of MES/MOM are amplified and complemented by the capabilities offered by digital technologies.

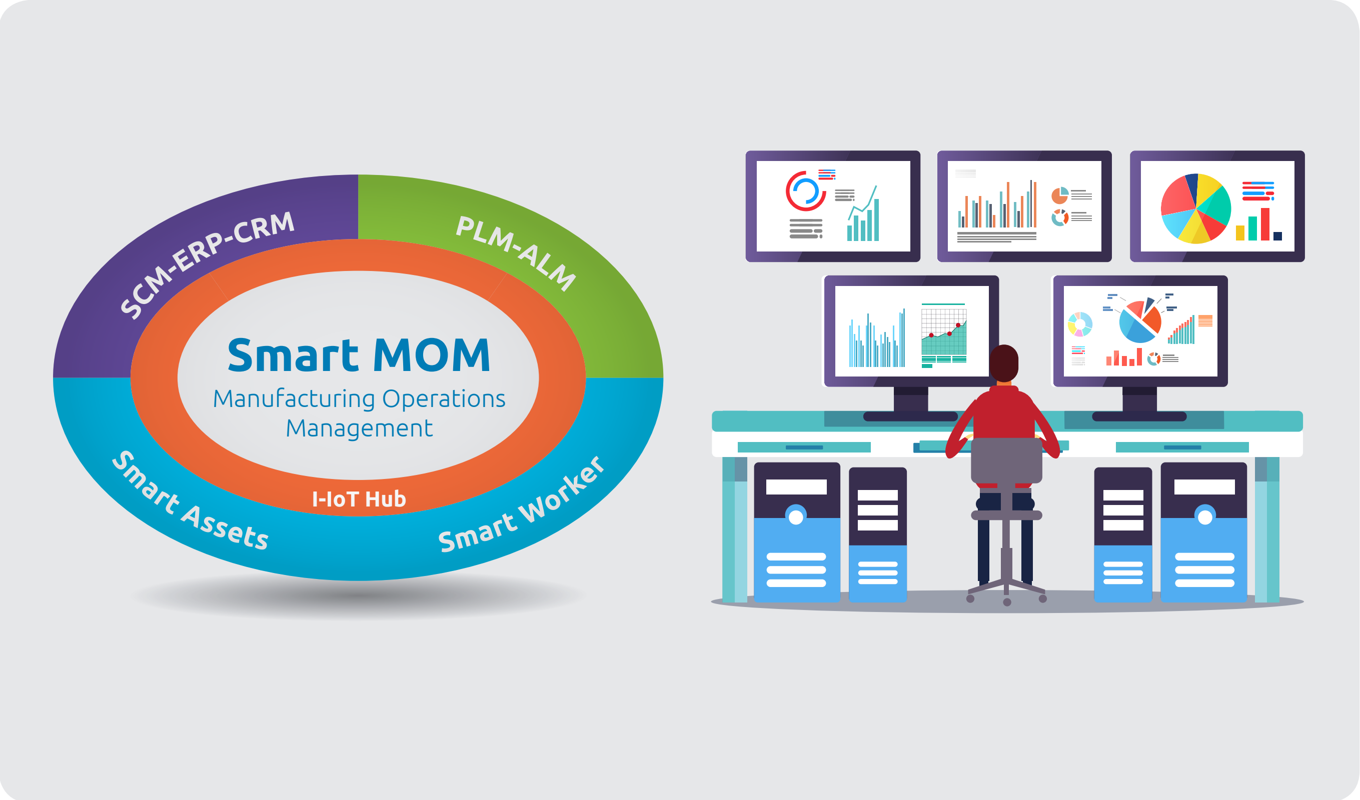
Real-time integration of production operations with the entire logistics chain

As stated previously, horizontal integration across the value chain is crucial today. Production operations are viewed as a segment —often particularly complex—of a globalized supply chain that needs to be tightly synchronized and very reactive to more and more versatile demand. The implementation of S&OP, MPS and DDMRP processes makes it possible to better anticipate this variability, however the production planner is subjected to new challenges.

Today, planning and demand estimation tools (APS & MRPs) are no longer limited by computational requirements and give almost instantaneous results with the reduction or even elimination of the so-far-so-useful frozen period—at least in theory. Until now, such planning activities have perceived the production segment as a black box—both physical and temporary—where a set of production orders are sent for a given period of time and last-minute changes only handled as exceptions.

With no more limits or technical constraints associated with calculations, it is normal in a world of technophiles to expect that production orchestration reacts dynamically with demand and thus is perfectly synchronized with the supply chain.

Real-time logistics and production operations management seem theoretically feasible. But now we



are dealing with other limitations—physical ones—the constraints of reorganization or reconfiguration of the production assets. Indeed, the amount of time necessary for switching production from one product to another is often important and determine the optimum size of production lots. It is a well known stake of both the discrete and continuous manufacturing industries. As this is one of the last barriers to totally dynamic production, it becomes paramount and one of major challenges of the industry. The ultimate vision for the industry 4.0 is to realize reconfiguration of production assets whenever required and in minimal time. Advances in robotization are part of the solution. The perfect example would be additive manufacturing or 3D printing that has the potential to reduce the batch size to one with almost no change time. Eventually this makes it possible for each product to be unique and personalized without impacting the daily capacity of production tools.

If we think of more traditional production tools involving machine shops and robotic assembly lines with complex flow of materials and semi-finished products, the activities become particularly difficult to orchestrate. In such scenarios, all exogenous events of the logistics chain must be considered, along with internal constraints specific to industrial functions in factories, in order to synchronize the supply logistics and production as closely as possible. The production supervisors of tomorrow will need to visualize and understand logistic flows and perfectly master the constraints of reconfiguring production equipment. Therefore, the ERP, APS, and flow simulation systems need to perfectly integrate with production execution systems like MES/ MOM.

Another important advantage, real-time information sharing and synchronization of the logistics chain can eliminate the famous "bullwhip effect"- the stochastic phenomenon resulting from variations in demand that becomes amplified and unpredictable towards the extremity of supply chain.

Allowing changes in products and/or production processes in real-time

As emphasized previously, demand versatility is driven by new ways of consumption and collaboration and, in particular, the ability to dynamically change a variant, color, quantity, or operating mode after the operations have started or even after manufacturing has begun. It could be a new customer need or urgent quality problem requiring a part's version change on the order in progress (for example retrofitting a part on an aircraft). Or it could also be an industry that particularly demands changes to products being manufactured (such as Formula One, satellites, or ship building to name a few).

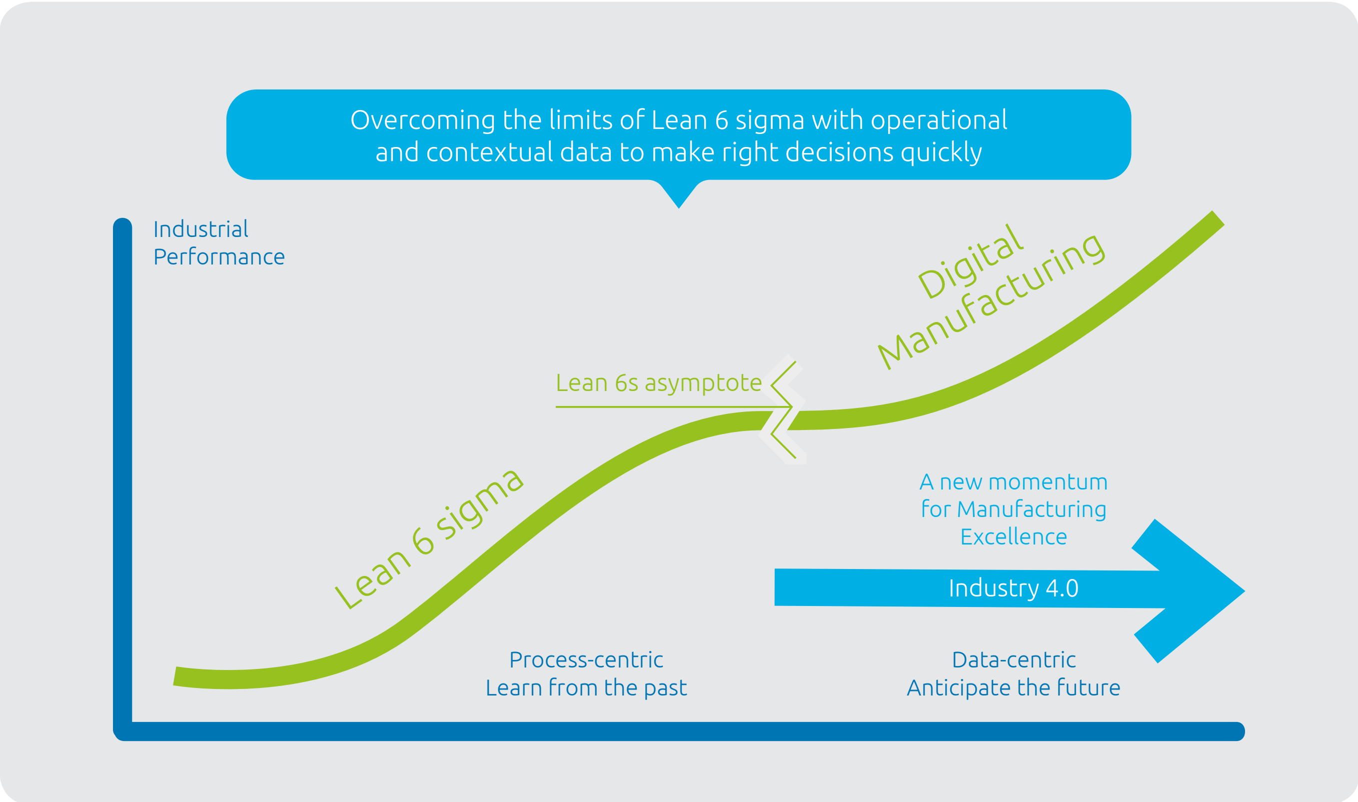
The impact of changes in product definition may be more or less critical depending on the flexibility of processes and production assets used. This can range from simple characteristic values (length, diameter, etc.) which is input data of the NC machine program, or on the screen of an operator. It may be a change in production line feeding, for example a rearview mirror and its fixing kit. Or eventually a complete change in operating mode, assets of production or even production site. For example if we choose a coupe car rather than a sedan.

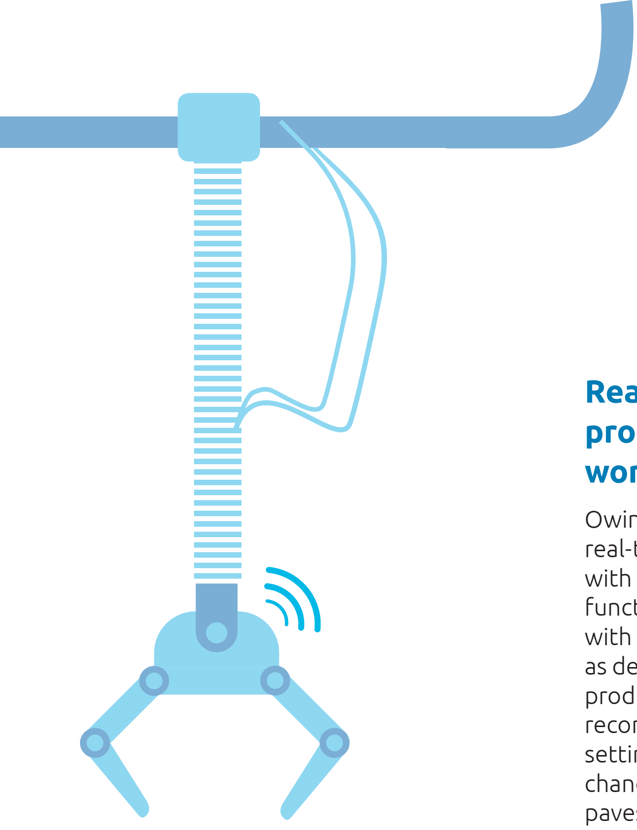
In order to react quickly to such changes to the product, it is necessary to control the impact on the supply chain, the production processes, and the associated resources. In order to realize this, the line supervisor must have a good knowledge of the product composition from the point of view of manufacturing (M-BOM), detailed production processes, necessary assets and resources, and their availability. He must validate and extend the changes in supply, resource allocation and instructions to the machines and operators. This requires a seamless communication between design systems for product, processes and assets (PLM/ALM) and execution systems (MOM / MES). Therefore, alignment of data models is essential to ensure digital continuity between systems which are rarely natively integrated.

Continuous improvement of industrial performance in real time

Since Taylorism, several methods of improving industrial performance have emerged. The most widely used include Lean manufacturing, Six Sigma, and the Theory of Constraints (TOC). Most companies that implement continuous process improvement use a combination of these methods to which they add information systems that support these processes and measure progress. These methods are generally focused on the analysis of production processes and seek to simplify them while making them more efficient. In the process of continuous improvement, diverse production data from systems and machines are captured and performance indicators—speed, efficiency, quality, errors, waste, delay and others—are constantly scrutinized. A few more advanced tools such as SPC control charts detect process drifts to trigger corrective actions in order to minimize the impact on production capacity.

The realization of the connectivity of people, of means of production and logistics makes it possible to capture enormous quantities of data that can then be analyzed now with very powerful computational and algorithmic capabilities. These new tools go much further in continuous improvement as they anticipate failures and constantly keep optimizing production performance by leveraging multiple inputs. Those are not only internal to production assets (number of cycles, temperature, pressure, type of defects, etc.) but also environmental parameters (hygrometry, ambient temperature, CO_2, etc.), or contextual (age of the captain, night shifts, supplier, customer, season, etc.), or related to logistics (mode of transport, etc.). Thus, data scientists build models that are able to determine the pattern of parameters for a given situation to be tuned for optimal performance and continuous improvement. Despite the diversity and amount of data being analyzed, such algorithms, when properly coupled with data capture tools, can trigger alerts and actions in real time. Thus, production supervisors have real-time dashboards consolidating all indicators and new means to perform cause-effect analysis in order to take best decisions at the right moment. Repeating such optimization loops again and again increases production performance significantly.





A new profile for a new role

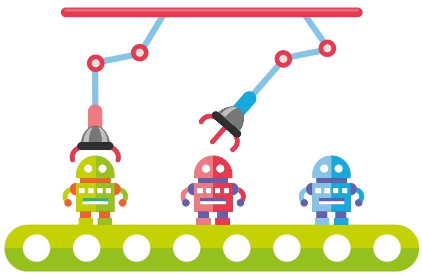
The role of "data scientist" has emerged with the advent of new digital technologies. The data scientist succeeds to "BI data analyst" by going beyond the simple representation of aggregated data. A true expert in AI algorithms, the data scientist is capable of developing prediction or optimization solutions specific to given problem types from industrial scenarios. S/he understands industrial challenges and, unlike the BI analyst, s/he is close to production operations and interacts directly with line supervisors and manufacturing engineers.

Real-time management of production activities by workshop supervisors

Owing to digital technologies and real-time integration capabilities with logistics chains and engineering functions, supervisors today deal with many unplanned events, such as demand fluctuation, changes in product definition, alerts on machines, recommendation of parameter settings, and even configuration changes of production lines. This paves the way for a new era of managing production operations, moving away from being a slave of business management and engineering functions to a much more autonomous mode. If ERP and APS systems continue to state, "when and how much" and PLM systems continue to indicate the "how and what," the exchanges need to be more dynamic and responsive requiring a decision-making close to the operations. Thus, the line supervisor gains access to a set of indicators, alerts, and analysis tools enabling him/her to make justified and documented decisions and better orchestrate production activities.

As we make such decisions, there is another critical area in Industry 4.0—the ability to act in real time. Indeed, everyone is focusing on data integration, data collection and intelligent data processing which is certainly critical for decision-making but not enough as the actions following decision-making must be efficiently executed and synchronized. While process manufacturers are already well equipped via the control tools (SCADA), discrete manufacturers are far from embracing tools for real-time operations control. In this area, the Industrial IoT platforms are often mono-directional, i.e. they capture data and information. Only a few of them can relay the control of machines and operators with the constraints of redundancy and security required to guarantee the stability and continuity of industrial production. Therefore, we see new dynamics in the implementation of MES or MOM solutions that are natively adapted to orchestrate production processes by integrating edge architectures close to production assets. A MOM solution that supports the execution of all production processes—manufacturing, quality, maintenance, material transit and storage—coupled or enriched with digital technologies is therefore the ideal tool to orchestrate activities in a production workshop.

The ability to quickly reconfigure a production facility when introducing a new product



As previously stated, the ability to quickly reconfigure the production tool is indispensable to respond to changes in demand. While it is already difficult to manage the change in product option, it is significantly more challenging when it comes to manufacturing a completely new product that is being manufactured for the first time. For a few very complex products such as cars or airplanes, setting up a machining process or a production line can take months and can significantly impact the ability to quickly introduce an innovative product to the market.

Here again, flexible means of production, ability to quickly simulate new shop floor activities and embracing faster pace of production ramp-up are particularly critical for the industry of twenty-first century. The physical and software resources need to be easily reconfigurable by the actors who define production settings. Machines, robots, assembly lines, and storage infrastructure must be mobile. The flow of materials and semi-finished products must be made adaptable, e.g. via automated guided vehicles (AGV). Production supervisors must be able to easily modify the business rules coded in execution software (MOM/MES) and logical controllers (PLC). Similarly, operators need to become autonomous, leveraging contextual work instructions posted in mobile devices. Finally, they can self-train better without disrupting existing operations thanks to virtual reality.

Smart MOM architecture and solutions

Wide and scalable

The need for horizontal integration and especially with supply chain favors the development of Smart MOM applications on cloud platforms that aren't limited by geographical constraints. Such solutions must be natively designed for cloud platforms in order to be fully scalable and easily deployable on any new site.

Real time interoperability

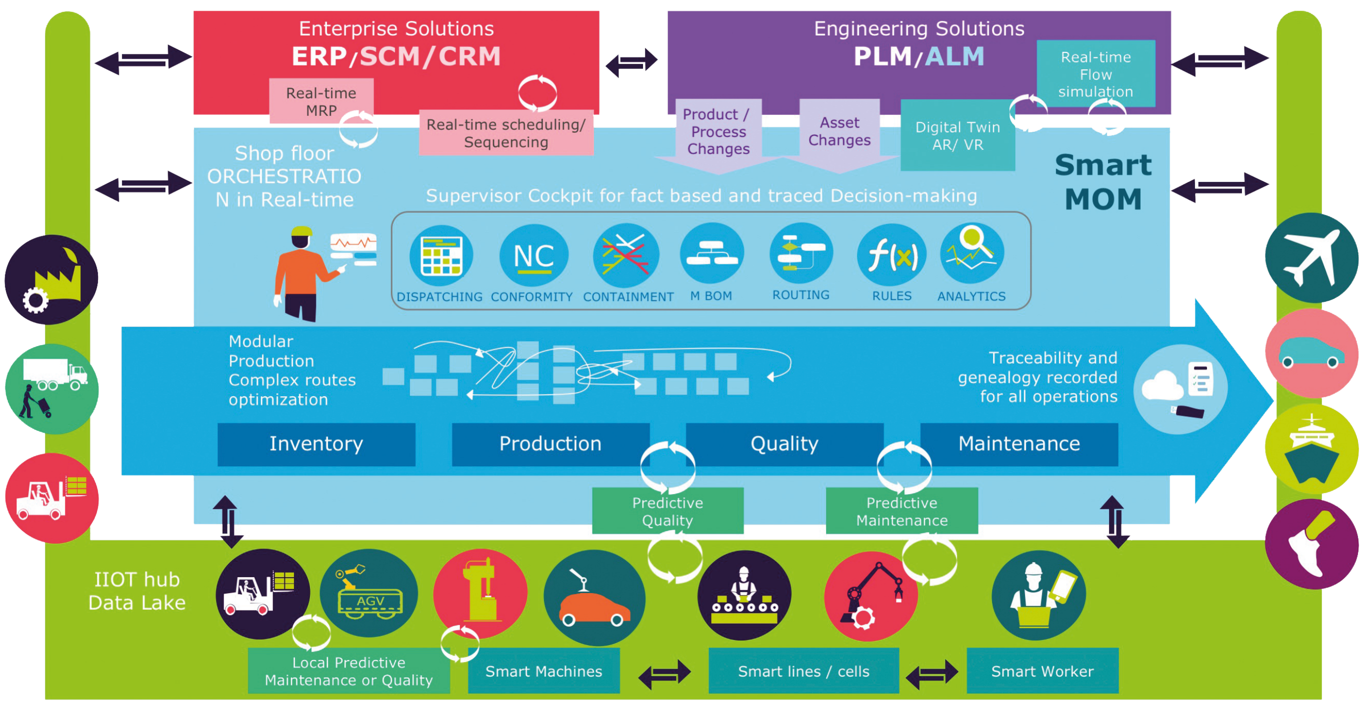
The architecture must also guarantee real-time communication with, on the one hand, enterprise applications (ERP, SCM, CRM, APS) and engineering solutions (PLM/ALM) and, on the other, with machines and industrial infrastructure. Solutions such as web services and micro-services must be preferred to guarantee the evolution of architecture.

The interoperability of the whole IS & T and OT ecosystem requires defining data model standards and communication protocols at the company level or even at the full supply chain network level. The alignment of data models is often overlooked. Many companies have indeed considered Big Data technologies would allow them to skip this difficult exercise. Ultimately they realize that it is an illusion. Irrespective of the solution used, it is always necessary to define a common "Esperanto" to perpetuate efficient communication between applications that need to evolve continuously. This is a big challenge in realizing an Industry 4.0 transformation.

A unique solution for Smart MOM does not exist today

No solution provider today offers all the components necessary to provide an integrated solution that meets all the requirements of the Smart MOM concept. However, the standard MES or MOM softwares that are already designed as synchronization platforms for operations in the factory, natively combine many functions. Their main challenge is to evolve towards fully scalable cloud-based platforms. In this respect, solution

Architecture Smart MOM : anticipation, agility and responsiveness



providers are historically cautious because applications are mission-critical and need to guarantee production continuity in the event of the failure of central computing, e.g. when ERP system is down. As a result, the historical architectures have allowed locally distributed implementations and served as a buffer in case the central server fails. Here, the transformation is slow but well committed to moving to cloud platforms with rapidly increasing reliability and performance. Going forward, only the control of the machines will remain on-premise as it requires levels of security, speed, and reliability (including redundancy) difficult to envisage with a cloud architecture. For this particular aspect, solution providers will continue to rely upon specialized local architectures, such as OPC UA.

A smooth and iterative approach, apps by apps

Smart MOM tackles the age-old gap of IT/ Enterprise and OT/ Control Systems that were implemented by different teams on very different technologies. This bridging layer between Enterprise and Control requires a smart architecture allowing traditional MES "transactional" functions to co-exist with highly scalable and agile data management and advanced analytics tools. A progressive evolution towards a truly integrated data architecture (transactions and analytics) is the next logical step. In order to completely do away with the rigidity of OT systems and take full advantage of the flexibility and scalability of cloud platforms, one can envision Smart MOM solution built on a "manufacturing platform" and being the backbone of shop-floor operations. Rather than designing their future MOM as classical "core systems" to be rolled out, manufacturing companies could break it down into granular "apps" that can be flexibly and progressively adopted by factories according to their dynamic requirements.

A win-win opportunity for MES/MOM software providers

Once the MES or MOM solution providers have achieved a real transformation to cloud-based platforms they will be able to position their solutions as the backbone of a Smart MOM ecosystem. Thus specific applications and technology enablers of Industry 4.0 - including artificial intelligence and virtual reality tools – will easily connect to such solutions. Specifically, the technology enablers that often remain in a state of proof-of-concept or as demos can be leveraged on these platforms and will mature as industrialized solutions. Thanks to this synergy, MES or MOM solutions that have become the underlying platform and cloud-based will improve their value proposition and accelerate the return on investment.

In case they do not succeed in this transformation, they will give way to new manufacturing platforms where MES / MOM features will be reinvented to gradually enrich stores of Smart MOM apps.

Conclusion

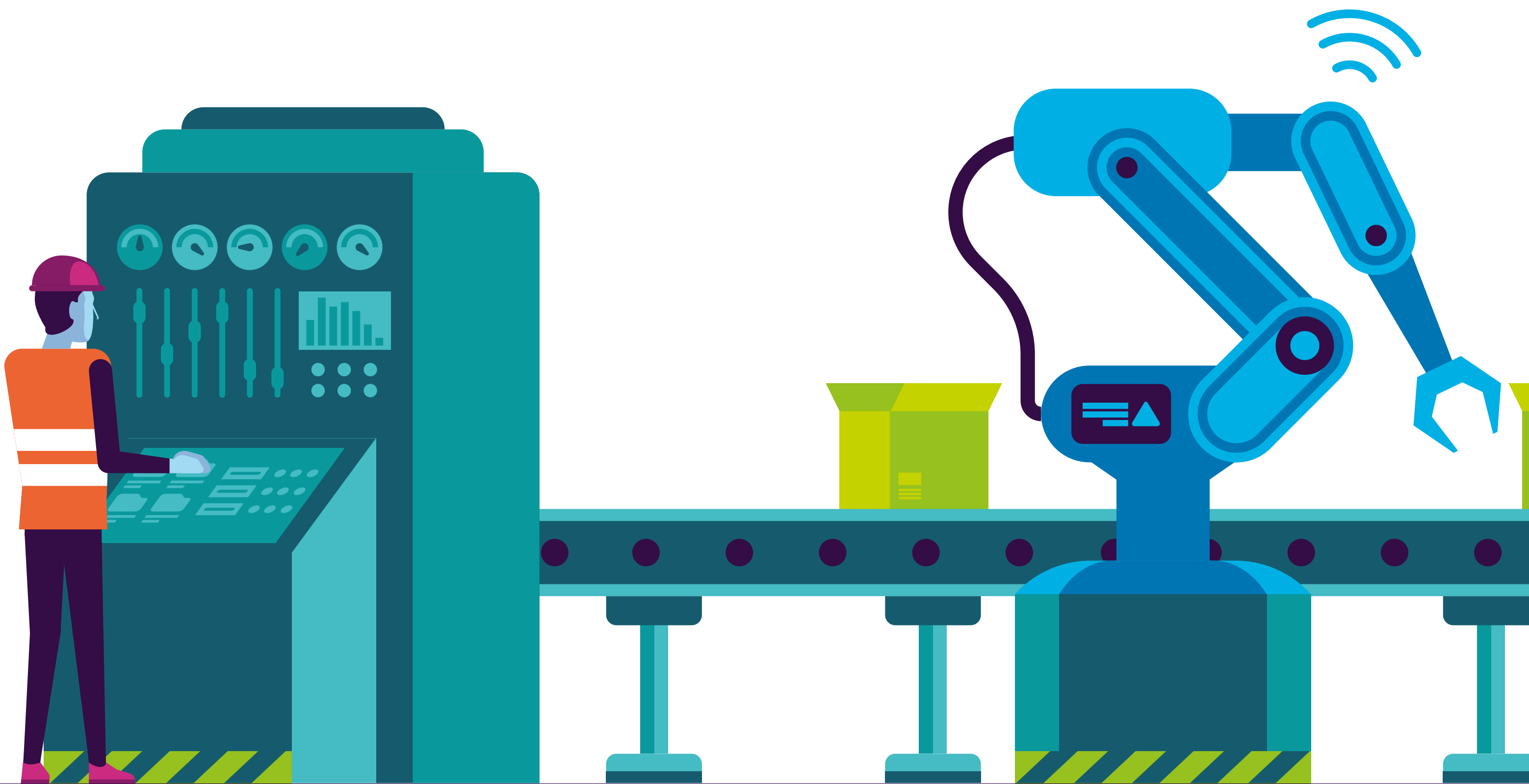
Capgemini's Smart MOM solutions and architectures are targeted at the challenges faced by industrial customers by connecting industrial objects and people with business processes. They enable to collect raw, technical, and quantitative data in real time and combine them with the contextual information specific to logistics and industrial processes. They also leverage digital technologies to analyze and use diverse data and adapt production schedules and tools in real time. Finally, as overall operational efficiency improves, factories become intelligent, capable of anticipating, reactive, adaptable, and reconfigurable.

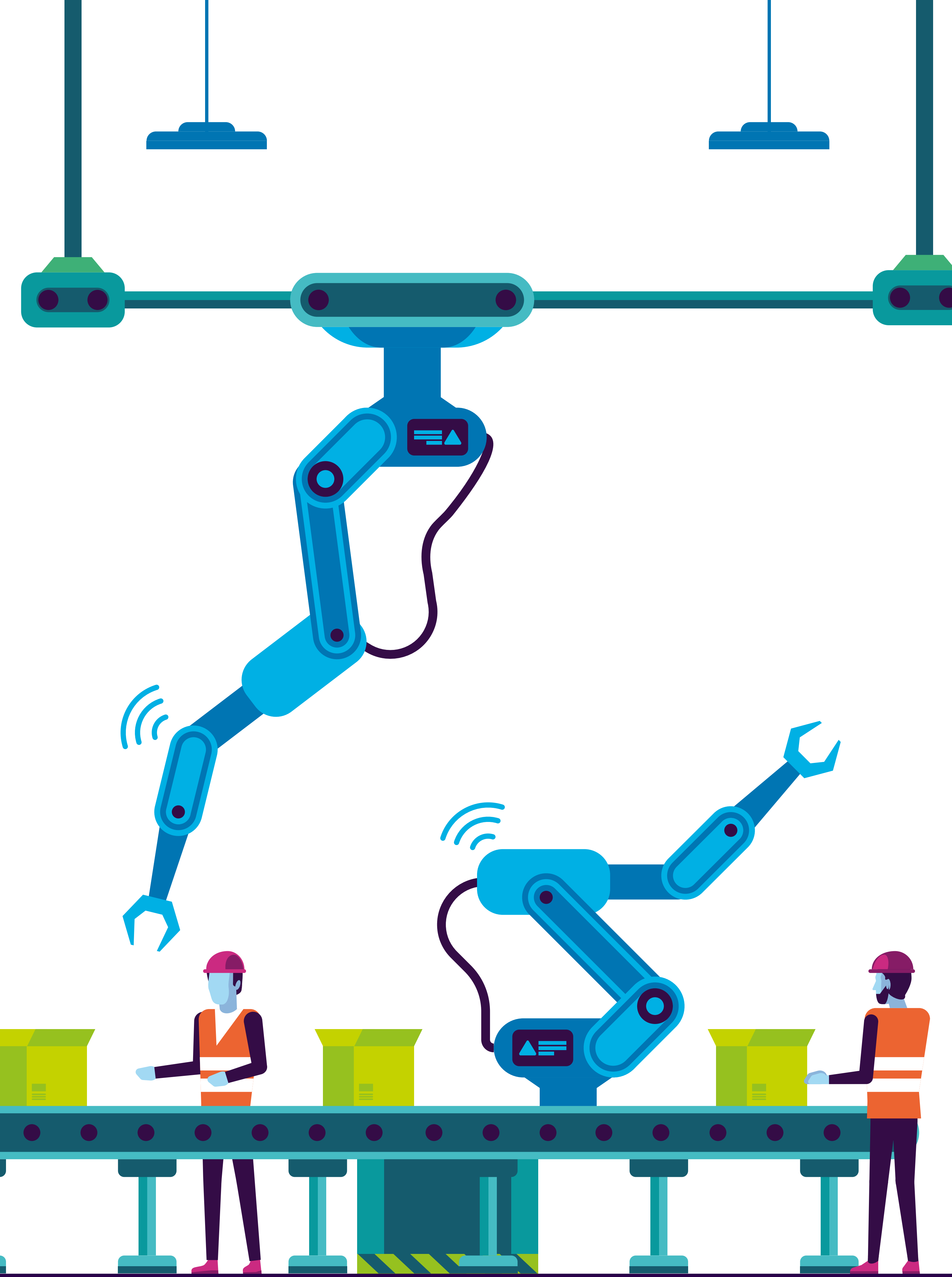
Epilogue: Going one step further

If we push our thinking to the extreme end of the spectrum, the reconfiguration capabilities of the means of production can be controlled with a deep integration of production assets with engineering and simulation tools (PLM, ALM, and digital twin). Production plant can then become hyper flexible and autonomous, similar to a 3D printer that is reprogrammable on the fly. Ultimately, it can mature to the extent that simply supplying raw material, energy and instruction is enough to produce any product as long as it is compatible with its field of production application.

One could therefore imagine the future of the discrete factory as a "black box" with an exit point where every product is different. For one factory it could be a computer, followed by a heart monitor, then a TV, that are exactly customized to an individual consumer's needs. For another, it could be an automotive engine, then a motorbike gearbox. Eventually a third one, would alternatively produce an AIRBUS A321, then a A350, and why not a Bombardier C-Series. Such factory can, of course, be controlled remotely by experts so that the plant can be installed closer to the consumer and becomes a local Production-as-a-Service available to various brands or product designers.

Does this seem too far-fetched, too much like a sci-fi movie? Well, it is not that far, proof-of-concept exists where a production line assembles motorcycles at one time and household appliances at the other. Immediate applications are possible such as the production of spare parts by additive manufacturing in close proximity centers that allow parts be delivered within the hour.





About Capgemini

A global leader in consulting, technology services and digital transformation, Capgemini is at the forefront of innovation to address the entire breadth of clients' opportunities in the evolving world of cloud, digital and platforms. Building on its strong 50-year heritage and deep industry-specific expertise, Capgemini enables organizations to realize their business ambitions through an array of services from strategy to operations. Capgemini is driven by the conviction that the business value of technology comes from and through people. It is a multicultural company of 200,000 team members in over 40 countries. The Group reported 2017 global revenues of EUR 12.8 billion.

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