

ARC WHITE PAPER

By ARC Advisory Group

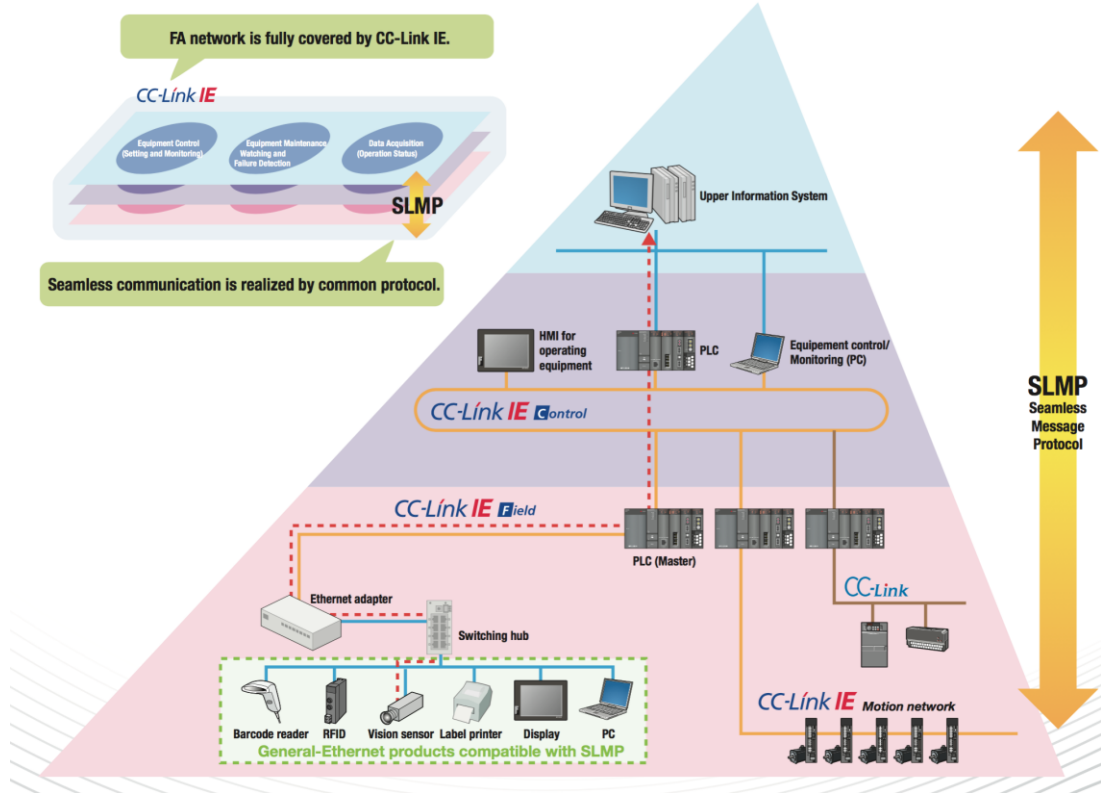
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The Industrial Revolution Continues

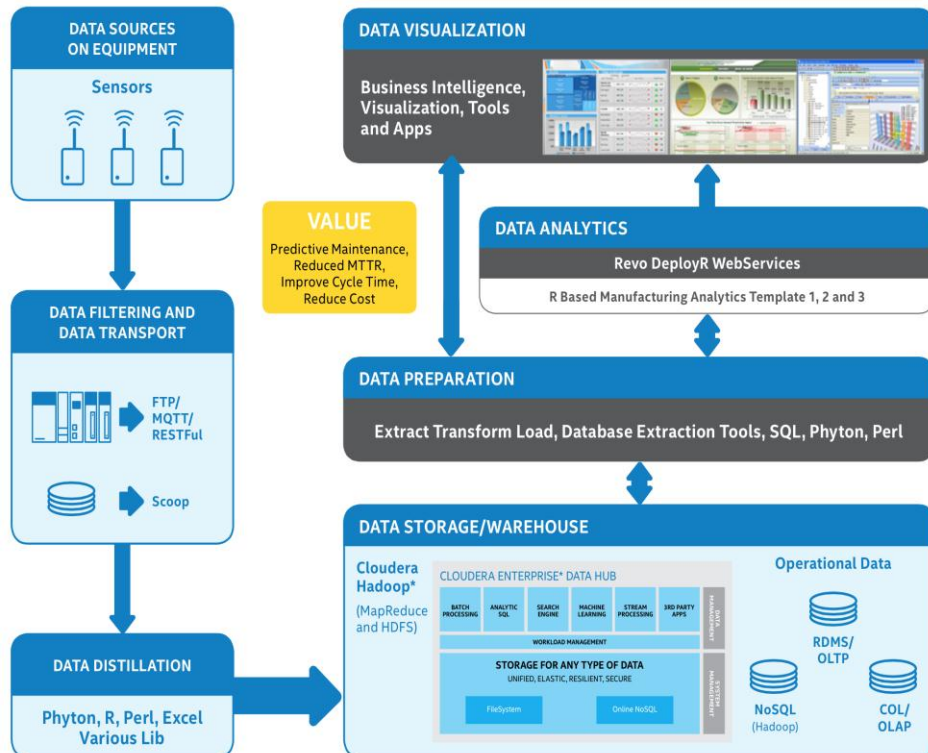
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e-F@ctory Core Architecture



e-F@ctory-based Industrial Analytics Implementation



Executive Overview

Trends and initiatives, such as Smart Manufacturing, Industrial Internet of Things (IIoT), and Industrie 4.0 are not mere hype; they are initiatives to stimulate manufacturing innovation, with the twin objectives of boosting industrial GDP growth and improving resilience during economic crises. Adopting innovations stemming from these initiatives can therefore be advantageous for all industry stakeholders. Companies should keep abreast of new technologies and innovations that different initiatives have to offer, and choose those that are likely to help in charting corporate strategy and achieving the company's goals. This paper discusses a series of commonly encountered objectives of smart manufacturing that can serve as a starting point for a company-specific approach. It also provides guidelines for companies to create, implement, and maintain a smart manufacturing strategy.

The case studies presented in this paper demonstrate that practical implementations are feasible and can create value today. However, with the pace of innovation in smart manufacturing and Industrial IoT it is imperative for companies to be agile and flexible. Although ideas and technologies undergo major disruptive changes in a relatively shorter timeframe, as for example with the introduction of industrial data analytics or Industrial IoT, in practice changes in industrial operations are implemented gradually.

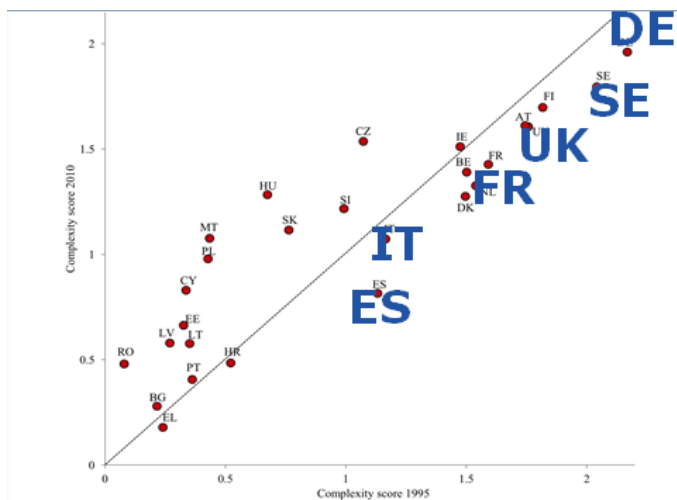
It is therefore important to establish a smart manufacturing strategy that is flexible and adaptable over time. We define requirements for a platform upon which smart manufacturing solutions can be built, and that is likely to be able to fulfill that role over many years. These requirements include scalability in scope, from local, machine specific to global multisite implementations; across devices and networks, from controllers to server parks, across disciplines and industry domains to provide cross-company applications. The e-F@ctory Alliance, founded by Mitsubishi Electric Corporation provides the platform that corresponds to these requirements. The e-F@ctory and the [CC-Link Partner Association](#) (CLPA) together unify more than 3000 partners covering a wide range of functionalities to build smart manufacturing applications. Four user case studies are described that demonstrate the versatility, flexibility, and scalability the Alliance brings to the table.

The paper concludes with a recommended process to enable companies to adapt smart manufacturing and industrial IoT to anticipated innovations.

A Smart Manufacturing Strategy

Initiatives, such as Smart Manufacturing, Industrial Internet of Things (IIoT), and Industrie 4.0 are not mere hype; they are initiatives to stimulate manufacturing innovation.

Before the shale oil and gas boom in the US, and in Europe after the financial crisis of 2008, the industry GDP was declining. These advanced economies needed a smart strategy to stimulate growth from manufacturing. The European Union started issuing manufacturing competitiveness reports to guide policy makers to stimulate the economy. The studies found that manufacturing contributes over-proportionally to exports, and increases the resilience to crises and capacity to recover after them. In addition, innovation in manufacturing is proven to stimulate manufacturing growth. As a result of that the EU innovation program [Horizon 2020](#) received a focus on manufacturing. Europe’s strategy inspired the member countries to set up their own programs in line with national needs, the most popular being Germany’s [Industrie 4.0](#). However, the UK’s [Catapult](#) program and France’s [Industrie du Futur](#) are also likely to create economic impacts.



Note: Dotted line denotes no change in complexity between 1995 and 2010. 'BE' combines Belgian and Luxembourg data. Source: European Commission (2013b)

The higher the manufacturing complexity, the better economic performance and resilience of the economy. Source: European Commission, 2013

The [Smart Manufacturing Leadership Coalition](#) (SMLC) was founded in the US to overcome the costs and risks associated with the implementation of smart manufacturing (SM) systems across production operations. A few years later, the [Industrial Internet Consortium](#) was created to accelerate the development, adoption, and widespread use of interconnected machines, devices, and intelligent analytics. Also, China and India started their initiatives, “Made in China 2025” and “IT panel of Confederation of Indian Industries’ (CII) Smart Manufacturing” as part of the “Make in India” initiative.

Manufacturing innovations in advanced economies boosts growth by increasing product value based on the technology content or complexity of

the product or the manufacturing process. Productivity innovations also contribute to competitiveness but are less unique strengths; because emerging economies strongly compete in this domain.

Manufacturing innovation initiatives, such as smart manufacturing and Industrial Internet of Things are smart strategies for sustainable growth

All these initiatives aim to improve either value or cost competitiveness or both. Some initiatives, mostly government initiated, such as Horizon 2020 or Industrie 4.0, and SMLC are connected to large and small companies, and are concerned about environmental footprint. Several initiatives also have social sustainability goals, such as well-being at work, jobs, quality of life, etc. We do then conclude that these initiatives are indeed a smart strategy for sustainable growth.

What's next: Industrie 4.1 or 5.0?

While Germany's Industrie 4.0 is at the fourth industrial revolution, Jeremy Rifkin published a New York Times best seller "The Third Industrial Revolution." This leads to the question of whether the industry is at the brink of a Revolution or if it's the industrial reality that is steadily evolving. If measured by hashtag frequency and publications, the perception is one of a revolution.

Historically, the transition between the first and the second industrial revolution was a gradual transformation where mechanization was initially powered by men, then by steam, and later gradually replaced with coal, electricity, and finally oil. For the third or fourth industrial revolution the situation is similar. Fossil energy is being replaced gradually with sustainable energy resources, and smart or advanced manufacturing technologies, including cloud computing and analytics, or self-optimizing systems, which have been around for a while.

However, in complex systems such as world economics and industrial developments, sudden transitions occur. Technology breakthroughs such as the transition from pneumatic networks to 4-20mA, and from 4-20mA to fieldbus are examples of such abrupt changes. While smart manufacturing systems are put in place more gradually than the concepts populating our minds, the introduction of some of its elements, for example the IIoT, is one of these abrupt changes.

Hence, a balanced view would involve smaller and larger, as well as faster and slower changes taking place simultaneously. Industrial companies do not have to choose between evolution and revolution: it is possible and re-

alistic to combine continuous improvement such as manufacturing excellence or lean manufacturing with step-change improvements; as business process improvement and radical improvements in manufacturing depend on strategy, goals, and priorities.

Smart Manufacturing or Industrial IoT?

As there are many definitions in use, there is sometimes confusion about the meaning or definition of the terms smart manufacturing and industrial



Advanced Manufacturing: WF Flow Former For High Precision Rotationally Symmetric Products. Source: University of Strathclyde, UK

IoT. The following distinction can help create clarity:

Smart manufacturing is more encompassing and includes all methodologies, processes and technologies that substantially improves the outcome of manufacturing, be it in the form of product value, quantity or quality, or in

the form of productivity or reduced environmental footprint. There are two main sources of improvement:

- Advanced manufacturing - This involves improvements in fundamental science or engineering, for example scientific advances such as photonics or chemical nanostructures or engineering improvements, such as modular production technology, additive manufacturing, or advanced forming.
- Smart manufacturing - This includes information, communication, or automation technologies applied to production processes and assembled to smart manufacturing systems.

Among these technologies we not only find Internet-enabled applications that we refer to as Industrial IoT, but also established technologies that

have potential in new domains and industrial sectors. For example, autonomous production optimization applied in the process industries could make its way into discrete manufacturing, and lean or pull manufacturing can be introduced in the process industries.

Choosing a Camp

In monitoring this domain, ARC Advisory Group finds that many initiatives and concepts are continuously developing. It is therefore challenging to have a detailed understanding of each of them. Rather than choosing to adopt a single initiative, that will remain a moving target for a while - and need to be monitored regularly for progress. We suggest to choose the most suitable elements among the many options provided by different initiatives. Each of these initiatives have their strengths, and many have the potential to bring benefits in operations. For example: Industrie 4.0 is building a very general concept together with an evolving set of standards to enable the implementation of interoperable and scalable interpretations of the concept. As a result many companies work on their interpretation of Industrie 4.0, and they are all different. France's "Industrie du Futur" instead, is managed as a collection of managed projects to find solutions to very specific goals. Also SMLC and IIC are project-oriented. It is therefore legitimate to pick and choose aspects of different initiatives that correspond to strategies and short-term goals of your company.

The following sections propose a methodology to build smart manufacturing solutions and make sure these can adapt to evolving technologies, approaches, and standards.

A Platform For Building Applications

The foundation for building smart manufacturing applications is a platform that is capable of connecting various kinds of equipment, such as machines, sensors, HMI, robots, printers, or drives; with PLC's, motion controllers, and IT applications in control or business networks. The vision for an ideal platform would be the following:

The platform components can be the user interface to enter operational instructions and display information about actually produced units and their quality parameters. The platform can be used to configure, monitor, and control equipment with the purpose of analyzing and improving the

equipment's performance and use. This can happen on a local basis with focus on a particular piece of equipment, or for a larger fleet of equipment possibly distributed over several locations.

Alternatively, these operations and maintenance functions can be informed by and displayed on higher-level applications, if there is a requirement for additional functionality or to coordinate these activities for several machines, lines, factories, or sites. The platform can be used, for example to send commands from manufacturing operations management (MOM) or orders from supply chain management (SCM) applications, and to collect and pass on production and equipment information to those applications. The same scalability from serving single equipment to multi-site production networks is available in building or connecting to systems to improve quality, energy usage, process, or supply chain performance, etc.

The platform provides high-bandwidth connections among all connected devices and nodes, enabling close-to-real-time exploitation of large amounts of sensor data from equipment, processes or units produced. The bandwidth is capable to handle future data volume requirements.

Equipment and connectivity is intrinsically secured and provide seamless information flows between the field, controllers, control network, and business network nodes; using open protocols, compatible with common industry standards such as Ethernet.

The platform enables building systems of cost-efficient standard-components that cover a wide range of functionalities, avoiding customization of non-compatibles.

Connectivity with virtualized, on-premise, private, or public cloud is straightforward. A distributed control network, or distributed nodes on a control network managing assets or quality are also "clouds," because they can be addressed transparently (or behave as a single application). The platform can connect with all these clouds.

It is simple and requires little effort to create connections. It is also easy to swap equipment and solutions to upgrade to more powerful or efficient solutions, and boost the solution's functionality and scope step by step. Adapting the system to changing requirements, plant configurations, product changes, demand volatility, and changes in regulations is also fairly simple.

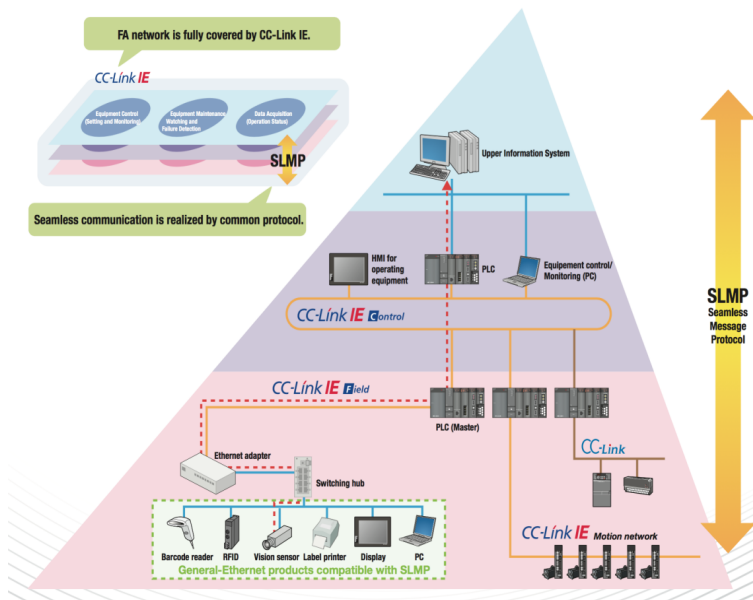
e-F@ctory, An Adaptable Smart Manufacturing Platform

The e-F@ctory Alliance, founded by Mitsubishi Electric Corporation provides the platform that corresponds to the vision developed above.

Mitsubishi Electric is an industrial conglomerate active in diverse industrial sectors, such as aerospace, automotive and transportation, semi-conductor, ICT, building and energy management, and automation systems. Mitsubishi Electric's experience in building solutions for improving manufacturing performance, led to the foundation of the [e-F@ctory Alliance](#), federating a large number of equipment and service providers in a wide range of electrical and automation engineering, automation and motion control systems, ICT, HMI, SCADA and MES, vision systems, industrial

networking, and more. The Alliance's offering is available to the external market via Alliance founder Mitsubishi Electric Factory Automation.

At the core of any solution that can be built from this large palette of products is the MELSEC Q-series controller and the CC-link fieldbus. The controller offers a flexible platform to develop solutions. For example one model has a CPU variant that runs compiled C-code, making it a very ensuring low cyber risk. This model can be configured directly or via alliance partner applications to act as gateway that enables direct connections with MES and other IT applications.



e-F@ctory Core Architecture

The connectivity is powered via the [CC-Link](#) or [CC-Link-IE](#) fieldbus. The latter is a recent version of the fieldbus with 1 GB/s bandwidth that has data, control, motion, and safety profiles; and can run on copper or optic fiber. It is the most widespread fieldbus in Asia with over 2200 member companies. The CC-Link fieldbus uses the so-called SeamLess Message Protocol (SLMP) that has the particular advantage of providing seamless connection from the sensor level, through the gateway control to the IT world. By connecting seamlessly with standard Ethernet, the range of connectable devices is virtually unconstrained.

The high bandwidth is designed to handle the large amounts of data created by smart sensors. Data volumes from the field are expected to continue to increase in an important way, when large amounts of new low-cost sensors will become available. The bandwidth enables small and Big Data analytics applications, which can only provide their benefits, when ample data is available. The shorter the transmission time, the smaller the latency to analytics results, thereby leaving more options to making corrective decisions.

The e-F@ctory and the [CC-Link Partner Association](#) (CLPA) unify more than 3000 partners, from which over 2800 are at the field level, over 250 at the control level, and more than 50 at the IT layers. The list keeps growing and together they do provide a very broad palette of functionalities to build applications from. Significant names in the list are among others: 3M, Atos, Baluff, Canon systems, Cisco, ePlan, Festo, IBM, Intel, Pepperl&Fuchs, Sick, and Wago. The web sites of the e-F@ctory Alliance and CLPA provide exhaustive lists of partners.

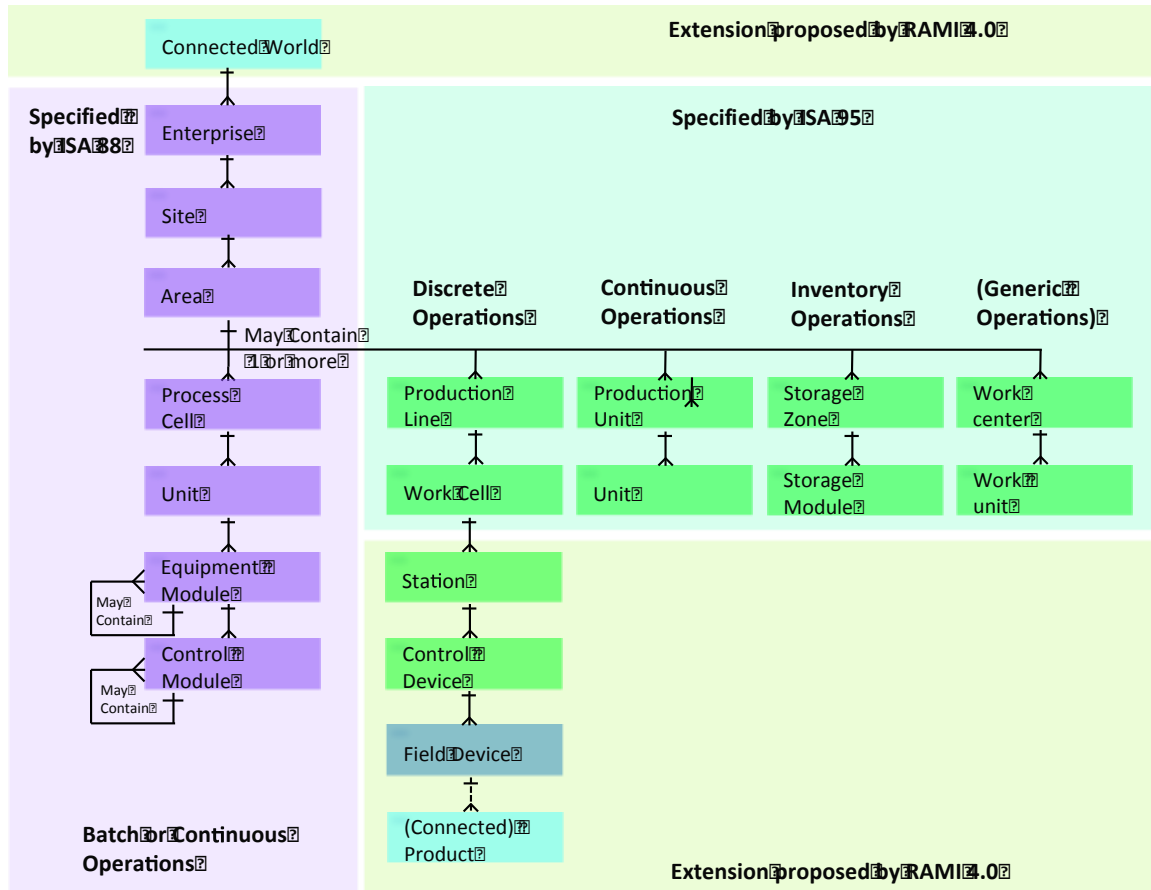
Once connectivity is established among equipment, automation, and IT a range of possibilities arise, empowering a wide variety of roles in the company with real-time actionable information.

Operations can operate equipment; execute production orders, monitor equipment statuses, and progress against production orders. For instance: using high-performance HMI applications built on the platform. The OEE and Energy Management Control Packs from Mitsubishi Electric are available to facilitate the support for activities in these domains.

Maintenance has an instantaneous view on the health and efficiency of the equipment, providing support in troubleshooting and scheduling maintenance or repair.

With the help of connected applications in the manufacturing operations management domain, the full scope of ISA-95 functionality becomes available; ranging from production operations, through quality and maintenance operations, to inventory operations, and providing production control to operations managers. Within the supply chain management (SCM) and enterprise resource planning (ERP) domains, the transparency assists in many ways. A good example of this would be how it enables planners to determine the latitude to adapt production plans to demand variations, and analyze supply chain performance.

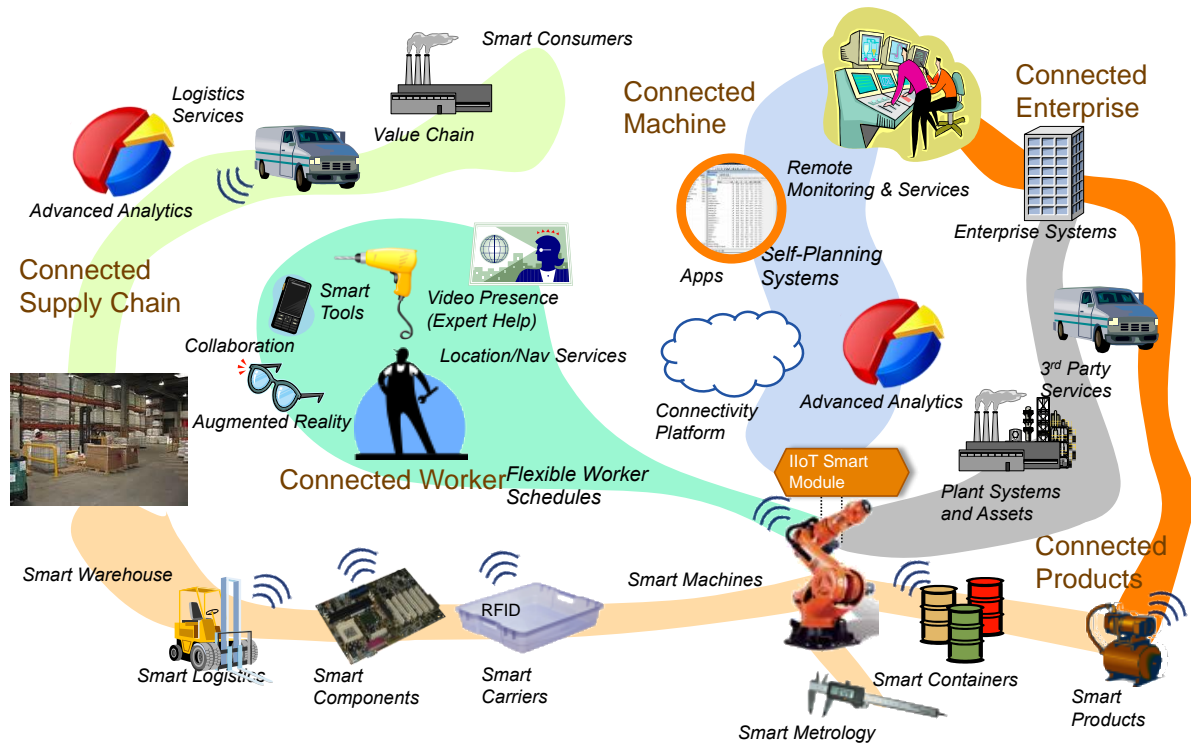
The e-F@ctory platform scales extremely well. It can be used for monitoring, operation and maintenance of a single equipment instance, fulfilling the same function for a distributed network of machines and equipment, but also for production assets of several lines, factories or sites, that can be considered to be a “production cloud.” It can feed local IT applications, for example a line-specific MES, as well as complex software applications globally coordinating operations, such as in the case of ERP or SCM. It can be used to create very lean as well as very elaborate systems, adapting to companies’ priorities and needs. The platform is ready for extensions of the network to connected products, as well as to a supply chain network linking production, logistics, service providers, clients, and other stakeholders through wired and wireless connections that IIoT generates.



e-F@ctory Scales To Each Level of the Industrie 4.0-extension of the ISA-88 and ISA-95 Physical Models. Sources: ISA-88, ISA-95, Adophs et al, 2015

This platform can provide small or Big Data coming from wide range of equipment to analytics applications that run locally, on the company network, in a private or hybrid cloud. Analytics applications are a fast growing domain because of the important benefits they can bring. Basic analytics provide graphical representations of historical information with

context, enabling fast understanding and decision-making. The next level applications are capable of forecasting and enabling proactive measures. The ultimate level is providing recommendations on how to run the process or the equipment, to fulfill production goals best. The Intel IoT pilot described below is an example of both a quality and asset analytics applica-



Emerging Smart Manufacturing Environment with Connected Companies, Manufacturing, Supply Chain, Services, Workers and Consumers

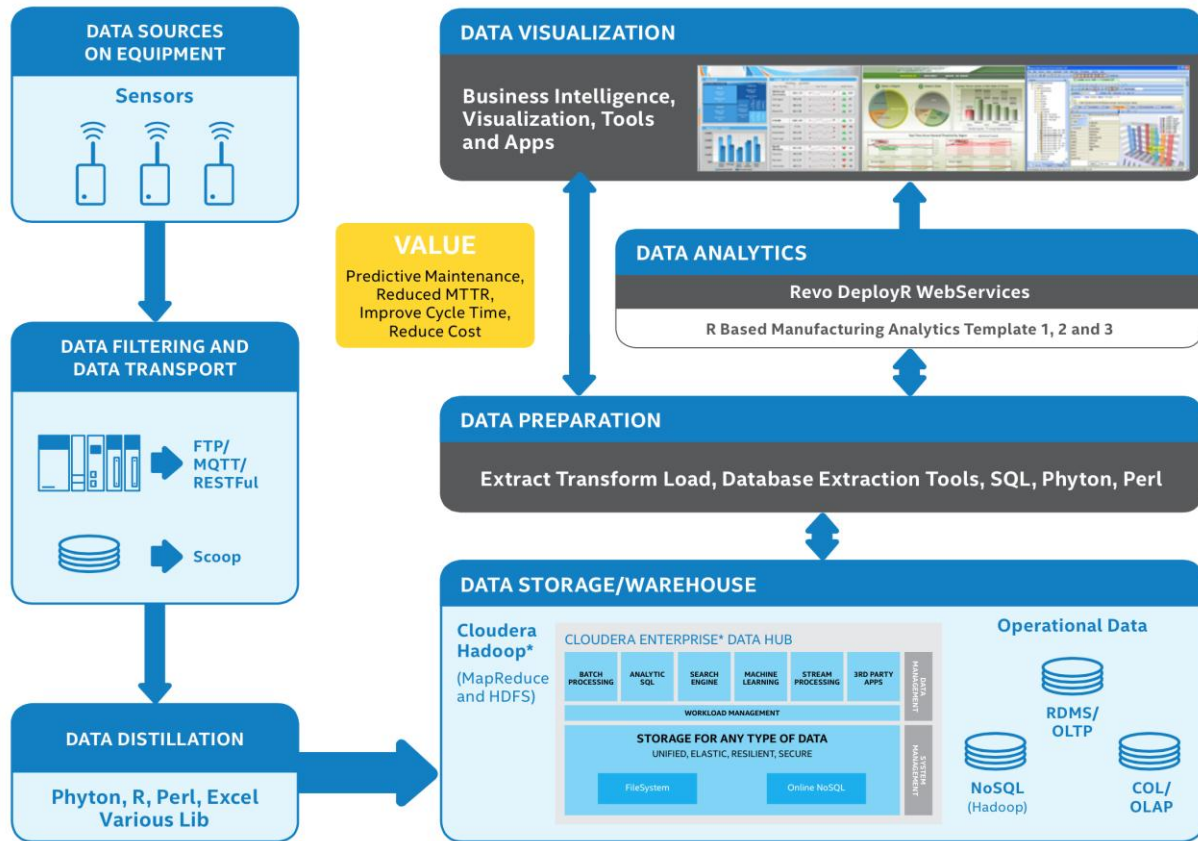
tion in the cloud. In addition, ARC Advisory Group provides three other summaries of e-F@ctory applications of the more than 20,000 installations worldwide, of roughly 5,000 installations connecting to MES and about 15,000 robot installations.

Intel Realizes Important Savings with IoT Pilots

Intel’s manufacturing equipment generates gigabytes of data per week, per unit; much of it was not put to good use. The data includes parameters, error logs, events from machines, and images from vision equipment.

In a pilot project at one of Intel’s semiconductor fabrication facilities, Intel implemented an IoT pilot based on the e-F@ctory platform to create actionable information from the available data. Intel used Mitsubishi Electric C Language controllers of the MELSEC-Q series, which offer robust network connectivity and high computational performance with high availability in

potentially harsh environments. CIMSNIPEr data acquisition and processing software was used to selectively transfer process data at rates on the order of megabytes per second via a [CC-Link IE](#) protocol for storage on a [Cloudera](#) Hadoop on-premise, private cloud-based Big Data Analytics Server (BDAS). Revolution R Enterprise from [Revolution Analytics](#) was used to analyze the data. The results are transformed into operational intelligence when presented on dashboards accessible through webservers. Not surprisingly, all the equipment used Intel’s high-performance processors.



Intel IoT Operational Intelligence Data Flow

The company evaluated three test cases:

- The first aimed to reduce incorrectly rejected units by automated test equipment. The analytics were able to predict 90 percent of potential tester failures to significantly reduce rejection of good units.
- The second one predicted issues in soldering related to process deviations, reducing equipment management downtime, and enabling proactive maintenance.

- The third case involved image analytics and automating visual inspection of marginal quality units. The image analytics reduced the selection time by a factor of ten compared to the manual method.

Intel published a detailed [white paper](#) on the pilots. In the presentation, the consortium predicted \$9 million (USD) of savings as a result of the pilots.

Improved Availability and Damage Avoidance at Municipal Water Treatment Plant

The municipal sewage treatment [plant](#) of the city of Rotenburg an der Fulda in Germany, needed to function reliably 24/7 to convert the water that the pumps lift from the biological sludge a few meters from the settlement basin into pure water. This process involved the pumps pushing the water into the settlement basin into aeration basin, where micro-organisms bring down pollutants. If these pumps failed, incoming water causes overflow of the settlement basin into the river Fulda, causing bacteriological pollution.



Municipal Water Treatment Plant of The City of Rotenburg an der Fulda

It turned out that the pump drives broke down much earlier than expected. Submersible emergency pumps could take over to avoid pollution, but a costly gearbox had to be replaced. In order to avoid this problem taking place repeatedly, the system integrator [Willich](#) and automation provider Mitsubishi Electric suggested a solution from the e-F@ctory partner FAG. The [FAG SmartCheck](#) solution was composed of a compact unit with vibration and temperature sensors that is attached to rotating equipment. Predefined configuration templates were available for different types of machinery that made installation quick and easy. The solution had a learning and a detection mode. After learning normal operation characteristics, the unit could be configured for different types of abnormal conditions, such as bearing damage, imbalance, misalignments, or temperature fluctuations. It could display the machine condition or transmit these to a

controller and via the latter to a web service to any mobile or static web-browser.

The detection of abnormal pump drive conditions becomes more accurate when inverter information is provided to the FAG SmartCheck unit. In the Rotenburg case, three drives and inverters were at a distance of fifty meters from each other, but fortunately an unused seven-core signal cable was available. Thanks to the flexibility of the [CC-Link SLMP protocol](#), the inverters were connected with the MELSEC Q-series control system that



**FAG SmartCheck Unit Installed At
Rotenburg an der Fulda Plant**

digitizes the analog frequency values. The same protocol enabled transmission of the digital frequencies to the three FAG SmartCheck units, each monitoring a drive. The control system could also transmit the monitoring information, including diagnostics and alarms, to a higher-level control or production system.

An eWON router, another e-F@ctory Alliance partner product, was implemented to enable the integrator to securely monitor and configure and display the controller and FAG SmartCheck remotely.

The solution was defined, wired, and installed in one day. The first warning came nine months after installation. After another three months the gearbox failed completely. With the accuracy of the warnings established, the city can schedule maintenance or repair before the gearbox is totally damaged. Scheduled maintenance makes it easier to maintain continuous operation, for example by taking precipitation forecasts into account. As a result,

plant availability, energy and maintenance cost improve with the smart manufacturing solution from the e-F@ctory Alliance partners implemented in the plant (for details, see Mitsubishi, 2014).

Improved Uptime, Maintenance Management and Project Efficiency at Honda's "Mother Factory"

The stable car sales in Japan, despite unpredictable car sales in the rest of the world, prompted Honda Motor Co. to create a new plant in Yorii, just

out of Tokyo, reducing considerable cost off the already lean manufacturing process for several small car models. The development of the plant involved 30 percent less assembly cost than its predecessor, among other benefits by applying advanced manufacturing technologies, such as high-speed presses and high-speed die-swapping; and by strongly reducing energy consumption of the paint shop. The processes were simplified to reduce the assembly time by forty minutes. Less robots weld higher than average number of points. (Greimel, 2013). In this context, automation needed to be highly reliable and accurate, that is, nearly 100 percent.

The company chose Mitsubishi Electric's Q-series PLCs with a CC-Link-IE fieldbus. The company holds Mitsubishi PLCs in high regard for their reliability and decided on CC-Link-IE for its high compatibility with the controllers, its high speed, and its rich functionalities. The functionalities required were a centralized management of the automation assets including setup and operational monitoring; maintenance management for health monitoring and diagnostics, and communication functions for safety controllers. The fieldbus network was built in sections, to reduce vulnerability from failures. At the same time the company required this setup and future extensions to be cost and effort efficient.

Centralized maintenance management and diagnostic functions of CC-Link IE helped the company in locating communication problems faster, thereby reducing the mean time to repair (MTTR), and improving operating rates. The company also found that expanding and adding safety functions is simple to do and reduces workload considerably.

The company was very satisfied with the solution, and is implementing a similar system in its new Mexico plant. (for details, see Mitsubishi, 2015:2)



Electrical Leakage Detection Mounted At the Base Of the Panel Boards

A Very Lean Maintenance Management Strategy

Nitto Denko Corporation in Japan has been producing chemical compounds used in the electrical and electronics industries, such as varnishes to protect motor coils, and moisture-proof coatings for electronic substrates. As in other chemical operations, fire and explosion hazards were important and strict regulations apply. In the Kameyama plant number 2, operational since 1969, the challenge was to

operate at low cost while maintaining safety levels up to regulatory standards. In the electrical and automation domain, the plant had vital wiring and cabling that were beyond expiration date as per the manufacturer's recommended duration because a systematic replacement was not economically feasible for the plant. As a result cabling could get overheated where the connections loosened or contact areas deteriorated. This could result in potential fire and explosion hazards. The company overcame this by using a yearly thermography inspection. The second issue was related to electrical leakage at points where the cabling insulation quality deteriorated. Some of these leaks were very difficult to spot, because the moisture that would trigger the leakage would evaporate without leaving traces.

The insulation-monitoring module of the MELSEC-Q PLC brand, known as QE28LG, could detect insulation deterioration on a continuous basis. Installed at Nitto Denko at each panel board, the system provided the technicians of the production technology section the opportunity to schedule maintenance before the leakage became dangerous, and at a well-defined location, thereby creating major time savings. The system also provides alarms at configurable thresholds. Nitto Denko Co. set a limit at 30mA for maintenance purposes, far below the second threshold of 200mA, representing the limit above which fire could be caused. Even if the threshold is exceeded once, an indicator light is set to orange or red.



Continuous and Threshold Monitoring Display For Electrical Leakage

The solution was compatible with Nitto Denko's budget, among other reasons, because the team was able to configure and install the system themselves. The design and programming of the monitoring screens took two weeks and the full installation was completed in a month, with a very limited number of resources.

The company mentioned that the experience with this project inspired them to re-examine other maintenance practices. "By organizing [and replacing some] maintenance activities, we can both improve maintenance quality and reduce maintenance costs."

The company considers implementing a similar system at plant 5, that was started up in 1985, and where electrical assets may become a risk factor. As the plant makes products in powder form that are potentially explosive, regulatory compliance requires appropriate protective measures (for details, see Mitsubishi, 2015:1).

Building Your Strategy and Applications

If the e-F@ctory platform and the application examples are inspiring, you may question how your manufacturing automation and IT strategy should evolve to take advantage of new and promising capabilities.

ARC Advisory Group observes a change in organization and approach in many companies we work with. As the boundaries between OT and IT blur, and automation, engineering, maintenance, manufacturing and back-office IT work much more closely together to establish common strategies than before. Although not strictly necessary, in some cases automation and IT organizations are merged to facilitate collaboration, while retaining domain knowledge within competence centers.

Based on earlier research ARC Advisory Group believes that manufacturing and automation IT strategies must relate to negotiation between technology stakeholders on the one hand and business owners on the other. This process is summarized as follows: The business owners have mid-term strategies and short-term needs. For example, they may decide to compete on price in a commodity product market, and have a direct need to slash cost in specific factories within a defined period. Technology stakeholders define the long-term technology strategy, for example standardization on certain technologies, vendors, methodologies, or upgrading obsolete systems. They understand the possibilities of smart manufacturing and industrial IoT. Ideally these stakeholders create and maintain a five-year rolling roadmap, and a short and mid-term project portfolio consistent with the roadmap. Business stakeholders will express needs for factory performance that technical stakeholders will translate in project proposals within the project portfolio. Steering committees oversee the process, provide prioritization and decide on admission of new projects to the portfolio. This process is iterative and needs to be repeated once or twice a year. Especially in the case of smart manufacturing it is important to monitor the progress made in the different initiatives – or ask a consultant to provide a concise overview – and update the roadmap and projects accordingly. ARC is available to provide more detailed guidance about this process on request.

We have provided elements for a technology strategy above. Here we want to provide input on translating business objectives into objectives for smart manufacturing systems.

Defining Goals

Several smart manufacturing systems have shown to be capable of delivering improvements of several percentage points, in for example Capex, energy consumption, OEE and reliability, and on-spec quality. It is therefore important not to anchor our minds on improvements of a few percent when setting goals, but thinking out-of-the-box and targeting radical improvements where possible. (For more information on cognitive biases, see Kahneman, 2011). Each company should define unique goals, but ARC observes many recurring goals. The discussion below may not be exhaustive, but provides a broad range of smart manufacturing objectives observed across a gamut of industries.

A few years ago, many focused on visibility of manufacturing and supply chain operations, and transparency among operational units (Rio, 2008). Today, operational intelligence takes the generally available manufacturing data, goes beyond historical visualization and applies analytics to make

Possible Goals for Smart Manufacturing

- Visibility and transparency
- Supply chain integrity
- Improved agility and flexibility while improving quality consistency
- Improved planning and scheduling
- Low cost asset management excellence
- Plant reliability, overall equipment effectiveness
- Energy efficiency

predictions and recommendations. With increased intelligence of instruments and number of sensors, numerous possibilities for optimization arise. So-called small data can be analyzed to predict behavior of a single piece of equipment and the combination of small data of an equipment fleet, or Big Data, can be used to compare performance under different circumstances and learn about utilization. The totality of data produced by a complex unit such as a petrochemical plant or an airplane is in the order of hundreds of millions or billions of data points per day. This reminds us that industrial data is often Big Data. Experience by our clients show that discovering patterns in data from

complex units, and making successful predictions requires domain knowledge in addition to statistics-based methods. The purpose of analytics is not to find the obvious correlations, for example that energy consumption is proportional to the quantities produced, but identify the otherwise difficult to identify correlations, or creating a ranking of most effective independent variables impacting process performance.

Other goals may relate to supply chain integrity, including tracking and tracing across the manufacturing and supply chain. With increasing amounts of products being counterfeited, representing losses for manufac-

turers and risks for users, anti-counterfeiting measures will become more important during the coming years.

With plants' increasing flexibility and agility in responding to ever faster changing demand, we expect that supply chain variability will increase as well. Small fluctuations in demand do create major instability in throughput in the production facility because of time lags and disturbances. (As an analogy imagine you have to follow a car in a city. If you want to keep up you need to speed in some sections, because of the delays introduced by traffic lights that only you have to stop for). These fluctuations can be damped by dynamically improved supply chain planning and manufacturing scheduling and real-time supply chain operating networks where partners accelerate information exchange using cloud-based solutions.

Variability is a complex subject. On one hand, manufacturing sites need to continue to apply methodologies to reduce variability in setup, change-over, and production time, as well as variability in product specifications when producing in steady state, or producing a specific product configuration. This leads to benefits from cost reduction and/or quality improvement. The latter has recently become even more important than before, because global companies want to be able to produce indistinguishable and interchangeable products on lines of different sites or geographies. These are requirements encountered in sectors, such as food & beverage, pharmaceutical, and automotive industries.

With increasing agility and flexibility product changeovers are more and more frequent. This is a form of variability that should not be diminished; on the contrary, changes should be made fast and at low cost. A well-known automotive major is capable of producing any model in any order on any line anywhere in the world. Changeovers must then be instantaneous.

The client case stories show that asset management excellence can create important benefits. A benchmarking study showed that some companies in oil and gas are capable of having high asset reliability at limited asset and maintenance cost (Laurens and van der Molen, 2009). The authors explain that the key is to make the right cost cutting decisions that maintain capability and value of the asset. Companies that excel in understanding their internal maintenance cost structures and streamline activities, cut waiting times, and avoid repeated or unnecessary tasks are poised for success. The Nitto Denko example suggests how automation solutions can help optimiz-

ing processes and the Rotenburg-an-der-Fulda example clearly shows how condition-based maintenance can reduce downtime and premature replacement. Finally, the Intel example shows the profitable outcome when a solution supports both maintenance and quality management. Similar synergies exist between maintenance and process safety, as in the Nitto Denko case, maintenance and HSE, or financial risk and compliance management, as for example in the case of driver safety of automobiles.

Plant reliability and OEE, energy management, and supply chain network optimization are topics that have received attention in the past, and potential for improvement remain considerable. As companies keep adjusting products and production assets to markets and needs, their optimization in these domains needs to be adjusted continuously as well. For example, several companies are able to reduce their energy consumption with several percent year-over-year, for long periods. In Europe and other regions, countries and companies will have to do so because they committed to ambitious energy saving targets, to comply with CO₂ emission targets. In addition, when applying new smart technologies, and using more real-time data combined with contextual information, and wider scope optimization goals, new potential appears.

Choosing Technologies

Most likely companies will take small steps, limit risks, and reap low hanging fruit. There is a lot of it and we encourage users to go after it. Transposing technologies and methodologies from one industry to another and cross-industry learning, are sources of possibilities to investigate (see p. 6.).

Using recent technologies to reap low-hanging fruit is another one. However risks increase. Asset analytics of rotating equipment is a source where companies are likely to find benefits at lower risks. For example, quality analytics maybe more involved and process analytics, maybe really challenging. In fact, users report that statistical methods are not sufficient in this case. On the contrary, they will also help discovering “the obvious,” for example: the energy consumption increases when production amounts increase, and so on. Experienced users testify that the knowledge of scientists and engineers need to be used to provide the known correlations, and that data science may be able to find correlations among the remaining unknowns.

Applying disruptive technologies is a third one. With the Intel example, we have suggested that high-performance industrial IoT applications are feasible and can be economical today. And this is real: there are business cases today for this type of application.

For the future, it can be anticipated that a patchwork of IoT solutions within a plant or enterprise can become as difficult to manage as the current landscape of production solutions throughout a global company, unless there is global standardization. Similar to the standardization in the operations management domain that has led to improved interoperability between application instances and reduced cost of integration, the industrial IoT domain will also require standardization for interoperability and scalability.

IT and OT converge, but industrial IoT and general IoT have been very close from the beginning. Policy makers and other stakeholders are very much aware of the fact that industry domains and other domains are tightly intertwined. In Europe and elsewhere, smart manufacturing strategies are developed simultaneously with other smart initiatives such as smart cities, smart transportation, smart healthcare, infrastructure construction etc. The European Commission, which targets broad adoption for economic reasons explained in the beginning of the paper, recognized in an early stage that standardization in IoT could not be done sector by sector, because fast adoption will only happen when IoT applications can be applied within domains and bridge across sectors. In March 2015, the European Commission started a cross-industry initiative, the Alliance for IoT Innovation, ([AIOTI](#)) as preparation for building large-scale IoT pilots. Working Group 3 within AIOTI has been assigned to consolidate reference architectures from different sources and propose in a very short period an IoT High-Level Architecture (HLA) and IoT semantic interoperability recommendations.

The purpose is not to create universal cross-industry standards, but scale across platforms and services built upon different standards. That is to make sure that different standards can work together, complemented with extensions that IoT require. If AIOTI WG3 would be capable to facilitate interoperability among industry standards alone (see picture on next page) this would be of enormous value to many industrial companies that have real difficulties or have to spend considerable resources to make different plants or plant sections that have adopted different technologies and standards, to connect and interact.

mains and incorporating the relevant ones in short-term actions plans or mid-term roadmaps.

This is similar to recommended business process management practices. A business process may work wonderfully at a given point in time, but may become outdated due to changing circumstances, and will then require update. An ongoing monitoring of the effectiveness of business processes is required. The example of Nitto Denko demonstrates that technologies and business processes are tightly linked, and need to be considered together.

ARC recommends to create multi-disciplinary teams to overlook smart manufacturing initiatives, similar operational excellence initiatives with a global support and project management function, and with the bulk of activities done by experts from operations contributing to an ongoing process in different groups establishing best practices, training, documentation and roadmaps (see above).

It is important to recall that the magic of people is needed to make things work. This implies that people need to be prepared for change, trained, supported and coached through transformation. This process works best when workers develop a positive vision that pulls them during the transformation, rather than when change is imposed. When leaders facilitate this process at each level of the organization, the process becomes scalable from a team to a complete organization (Boyatzis, 2006).

People need to be made part of the system, rather than engineered out of the loop (Rust, 2015). When they learn to trust their systems and feed them with reliable information, and the systems provide contextualized information through easy to use interfaces that enable the people to prioritize, act and make decisions with insight and compassion, an optimal situation arises, beneficial to people, systems, and their organizations. The e-F@ctory and its associated alliance looks to be a viable way to achieving this goal

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Author profiles

Dr. Valentijn de Leeuw

Vice President
ARC Advisory Group
vdeleeuw@arcweb.com



Areas of Expertise

Focus areas include Organizational Change and Effectiveness, Business Process Improvement, Value-based Performance Management, Governance, Project Management, Knowledge Management, Operations Management, Asset Management, Innovation and Engineering as also Smart Manufacturing and Industrial IoT.

Extensive experience in best management practices in process industries. These include chemical, polymer, metals, energy, utilities, food, pharmaceutical and petroleum manufacturing. Experience includes knowledge of unit processes, simulation and modeling and business practices utilizing application software designed for manufacturing operations. Experience in aligning organizations, strategy, business processes and technical architectures.

At ARC, responsibilities include research and consulting in process industries, with focus on clients in Europe, Middle East and Africa (EMEA).

Valentijn holds a PhD of technical sciences from Delft University of Technology in the Netherlands in cooperation with Ecole Nationale Supérieure des Mines de Paris and IFP in France and also holds a Masters in Chemistry from Utrecht State University located in The Netherlands.

Valentijn acts as independent expert-evaluator of research projects for the European Commission in the information technologies and communication, and social sustainability and worker attractiveness in manufacturing domains. Valentijn represents ARC in the Alliance for IoT Innovation.



Analyst: Valentijn de Leeuw

Editor: Sharada Prahladrao

Acronym Reference: For a complete list of industry acronyms, please refer to www.arcweb.com/research/pages/industry-terms-and-abbreviations.aspx

ERP	Enterprise Resource Planning	OEE	Overall Equipment Effectiveness
HMI	Human Machine Interface	OT	Operations Technology, Automation plus MOM
HSE	Health Safety and Environment	PLC	Programmable Logic Controller
IT	Information Technology	SCADA	Supervisory Control And Data Acquisition
ITC	Information and Communication Technology	SCM	Supply Chain Management
IoT	Internet of Things		
MES	Manufacturing Execution System		
MOM	Manufacturing Operations Management		

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