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Value-Driven CFX Case Studies Supporting Smart Manufacturing

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Abstract

The Connected Factory Exchange (CFX) standard is now a year old. During this time, many applications of CFX have been discussed, and projects started that focus on CFX related values that support the changing business model of manufacturing. In this paper, two diverse examples are discussed, illustrating how the adoption of CFX is the critical factor in the achievement of each result.

Introduction To The IPC Connected Factory Exchange (CFX) Standard

The release of the Connected Factory Exchange (CFX) standard, heralded a sigh of relief throughout the industry, including assembly manufacturers, machine vendors, and solution providers, who now see critical barriers removed for the success of collaborative Industry 4.0, that has the promise to double productivity levels, eliminate quality issues and create the truly flexible factory. For many years, the trend towards value obtained from data has been recognized, made more important as factories experience increasing fluctuation in product demand, resulting in higher mix and smaller lot sizes. The timing for the success of CFX was dependent on a number of factors, including the business need to reverse the trend of declining productivity, IIoT technology, the limitations of proprietary data formats in an interoperable environment, and modern software architecture.

The definition and content of CFX is consensus-based, covering all aspects of assembly manufacturing. Over the two years spent developing CFX, more than four hundred participating companies have been involved, developing and defining message content that represents non-proprietary, technology orientated design, to meet the most progressive requirements for Industry 4.0. CFX was specifically designed to kick-off practical adoption of Smart, Industry 4.0 assembly manufacturing, in a way that was inclusive and cost effective for everyone in the industry. With other standards failing to deliver the specific needs and complexities required by electronics manufacturing, a new approach was needed, that would satisfy the demands of Industry 4.0. A key element of the standard is to provide an IIoT-based plug and play environment across manufacturing.

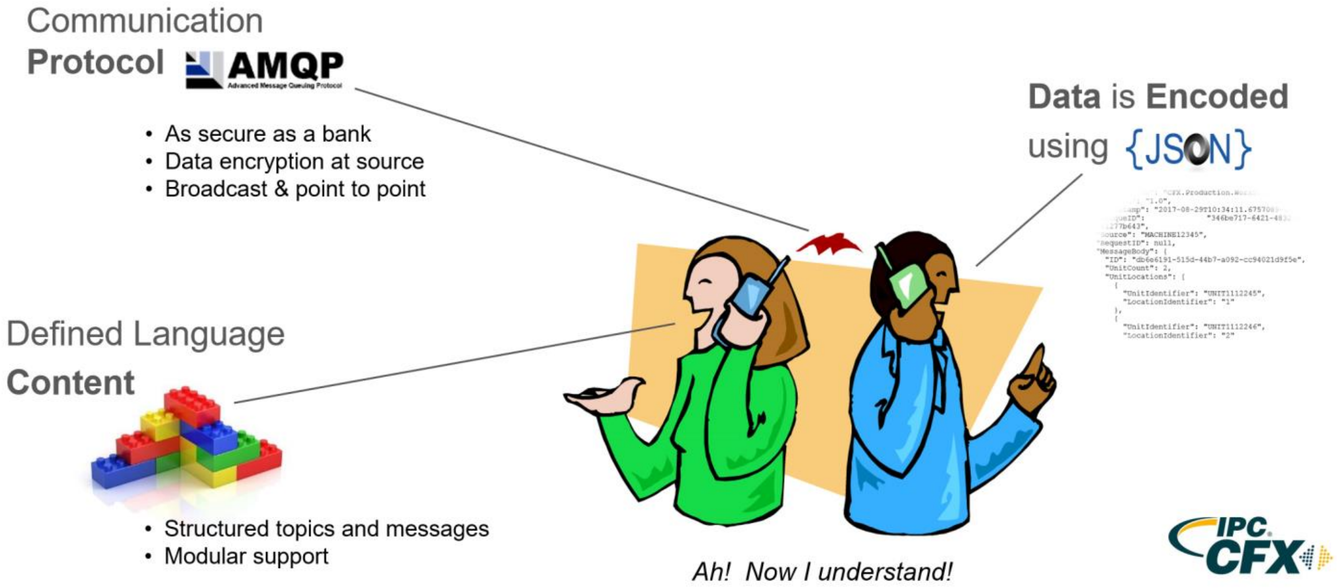

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Figure 1 – CFX Components

There are three key components of the CFX technology:

1. *Communication Protocol:* The open-source AMQP v1.0 protocol is used to transfer IIoT data from point to point. This was developed by the banking industry for the purpose of secure, encrypted transactions of data across any

network, and is widely in use in mission-critical areas. AMQP v1.0 uniquely provides two distinct data transfer mechanisms. For general messages, a broadcast structure is used, whereby a broker is used to manage and deliver messages reliably to any number of recipients. Where direct message exchange, for example commands, is required, data can also be sent point to point, such that operations can be actioned and confirmed. This duality of message types addresses a critical requirement for manufacturing, as general data must be shared robustly without a drain on the resources of senders, yet time-critical direct operations must also be supported.

2. *Data Encoding:* The JSON data format was chosen as being the most modern and efficient way to structure data messages, with software being able to simply parse the data needed, yet also being human-readable. Most software developers today are familiar with the JSON format, which is used in the majority of web-based systems.
3. *Defined Message Content:* All messages sent with CFX use the exact same content definition and format, no matter where the data originated, which is an essential requirement for plug and play. Though this creates quite a rigid environment, it means that any receivers of CFX messages know exactly what the data represents, without any need for translation or middleware. The flexibility required to support newer machines and processes is provided by the modular topic-based structure that CFX adopts, such that any machine, past, present, or future, can be digitally modeled using selected relevant topics. The CFX standard is updated roughly twice per year, in order to expand the scope of manufacturing technologies to which it may be applied. The defined message content is the most critical and unique element of CFX, which all other standards to date have not succeeded in delivering.

CFX defined topics, sub-topics, messages and data structures are clearly defined, with layers progressively containing more technology specific details. From the simplest of dashboards, to the most complex analytics reporting and control systems, the selection of CFX messages is simple and flexible. The top-level topics break down as follows:

- *Production:* Data related to the movement and processing of production units, including all process information, measurements, test results, readings, tools used etc. A complete and detailed set of process traceability.
- *Resource Performance:* Data related to the efficiency and productivity of machines and other processes, including details of state changes, such as down-time, maintenance events, setup procedures, and any other actions that happen that influence machine added-value versus non added-value activity.
- *Materials:* Data that relates to all material utilization, including consumption, usage, spoilage, verification, scrap, and transportation. The messages together provide a complete and exact traceability of materials across the whole factory.
- *Information System:* Data about work-orders and schedules, the creation of unique production unit IDs, as well as measurements from non-production related sensors including energy consumption, temperature and humidity etc.

In order to accelerate the adoption of CFX, IPC provides an open-source Software Development Kit (SDK), such that much of the development cost and lead-time required for CFX implementation is avoided. Simple CFX support examples have been achieved in as little as three hours through the use of the SDK. As well as the huge cost and lead-time saving, the SDK allows CFX to be cost-effectively retrofitted to older machines that may no longer be supported under normal conditions. One machine vendor has already stated that CFX will be made available on every machine that they have ever sold into the market. CFX has also been incorporated into tools, such as soldering irons and torque wrenches, and has been used by “in house” IT engineers to provide connection to bespoke machines, such as functional test jigs and bespoke systems. For very old machines that do not possess any computing power to support CFX, there are commercial solutions based on inexpensive hardware, such as the Raspberry Pi credit-card sized PC, plus a similarly sized and priced I/O board, that can act as a CFX data generator when connected to the machine itself. Engineering services are needed to personalize the internal software, including any necessary electrical connections to the machines. Such is the simplicity of CFX, internal IT engineering departments are also able to develop their own endpoint solutions for use with functional test jigs etc.

IT vs. OT Systems & Network Security

Since most production machines now have the ability to connect to the internet, there is significant concern about IT security when connecting the shop-floor network (OT) to the main company IT network, especially where sensitive products are being made. Many IT teams insist that there has to be no electrical or other physical connection between the strictly managed company IT network, and what takes place on the shop-floor, making the Smart connected factory an impossibility.

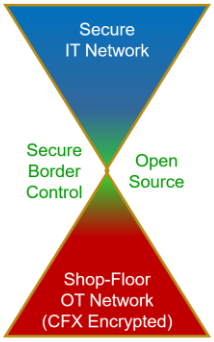

Figure 2: CFX Border Control

Uniquely with CFX, a secure bridge may be developed and used to connect a single border-control device in between each network. The software on the border control device will have a complete block of any and all network activity between the two networks, except to allow CFX data through one port. The border control software then provides monitoring of all aspects of the CFX data stream, blocking any unrecognized activity. In the case of CFX, this is simple to achieve, as CFX is the only standard that is based on fixed data content definition, such that all data can be specifically authenticated against the standard in real time. Both the CFX SDK and the AMQP v1.0 host software packages are open source, so the source-code can be scrutinized by the IT development team, who incorporate it into their own border control software, accelerating the development, yet with no dependencies on third parties for the security of the network.

CFX Interoperable Smart Manufacturing

The use of CFX provides a revolutionary layer of IIoT-based standardization, such that multiple interoperable solutions can together provide Industry 4.0 values. Business goals based on Smart manufacturing can finally be addressed, no matter what tier or sector the manufacturing company belongs to. From the machine vendor perspective, CFX is provided as a native interface from each machine that supports all customer needs. Going forward, the vendor therefore has only one interface to support and maintain, rather than an average of around thirty bespoke legacy customer interfaces. Machine vendors can also access data from other machines and lines in the factory, as well as factory-layer data, which they can use to further augment automated optimization of their machines and lines, providing their own Industry 4.0 solutions, without the need for complex inter-party contracts, associated NDAs etc. For IT teams and solution providers, applications using CFX are interoperable through the single CFX interface. Key IIoT-based MES solutions now connect to any and all machines across the whole factory through a single interface. Instead of the majority of IT solution R&D resources being spent on interface creation, custom deployment, support and maintenance, all effort can now be focused on development of the next generation of Smart factory applications.

Journey to The Cognitive Enterprise

There are five stages of readiness seen throughout the industry as to how companies are approaching digital manufacturing.

1. *Exploration:* Having a basic lack of knowledge and understanding about the role of digitalization in the factory and how it can transform the business, considerations are to look at IIoT and IT architectures, creating a vision of IT modernization, supported by selective proofs of concepts.
2. *Instrumented:* Companies have started to get basic data capture from machines, including product history, and are thinking about applications that it can be used for. Some consideration is being made into integration and standardization of data.
3. *Connected:* With data available from many machines, the attention moves to the value of data content and how multiple sources of data can interact. Analytics solutions, complex dashboards and traceability applications are being considered.
4. *Intelligent:* The integration of systems has been achieved, with software solutions delivering Smart values in the areas of machine learning, closed loop systems, Lean supply-chain, exact traceability and more, all based on contextualized data.

5. *Cognitive:* Factory operations are intelligent, self-learning with AI. Many advanced uses of contextualized data are present, both locally and/or cloud-based.

The value from data increases exponentially as each stage of readiness is passed. With the majority of companies in the industry currently stuck between stage 1 and 2, it is extremely important that the opportunity is taken when making decisions, to ensure that their manufacturing operations are able to follow the complete journey, without obsolescence and incompatibilities on the way.

Turning Data into Value: Contextualization

There are two essential elements that represent significant barriers to moving forward with Smart factory development. One is the standardization of data format and content, and the second is how to combine the data from many different sources to create value. Though there is a huge potential using data to find out previously unknown facts about influences and effects on production quality and performance, the values will fundamentally depend on how much potential value exists within the data itself. Take the example of a machine stopping, perhaps due to no product arriving to be processed. The CFX message from a machine can only contain information about what it has experienced internally, such as “no product arriving”. There is no amount of statistics that can practically use this data without contextualization with other events that contributed to create this scenario. The reason for the “no product” is most likely due to a related upstream issue, which could be caused by a breakdown of a different machine, a material issue, schedule issue, or in fact any one of many different other reasons. Unless the real cause is determined, there is very limited value from statistical analysis of the originally reported condition. The IIoT-based MES layer identifies event data relationships based on knowledge of the live production configurations, product design as well as live production data, materials flow, tool utilization and many other key operations. Contextualization increases the usable value of data from around 20% in the case of raw data, to nearly 100% for contextualized. Performing the contextualization of process data as it happens, means that trillions of repeated cycles of analytics can be avoided, without loss of detail, gaining greater value, saving significant cost and time taken to achieve results. The sheer volume of data storage required is also reduced significantly through contextualization, with the removal of data duplication and redundancy.

The Three Layer Smart Factory Model:

Looking at Industry 4.0 holistically makes it immediately clear that there is no single solution, that interoperability of machines and applications is the key for success. The following three layer model illustrates how original data, both raw and contextualized, is utilized in different ways throughout the hierarchy of manufacturing.

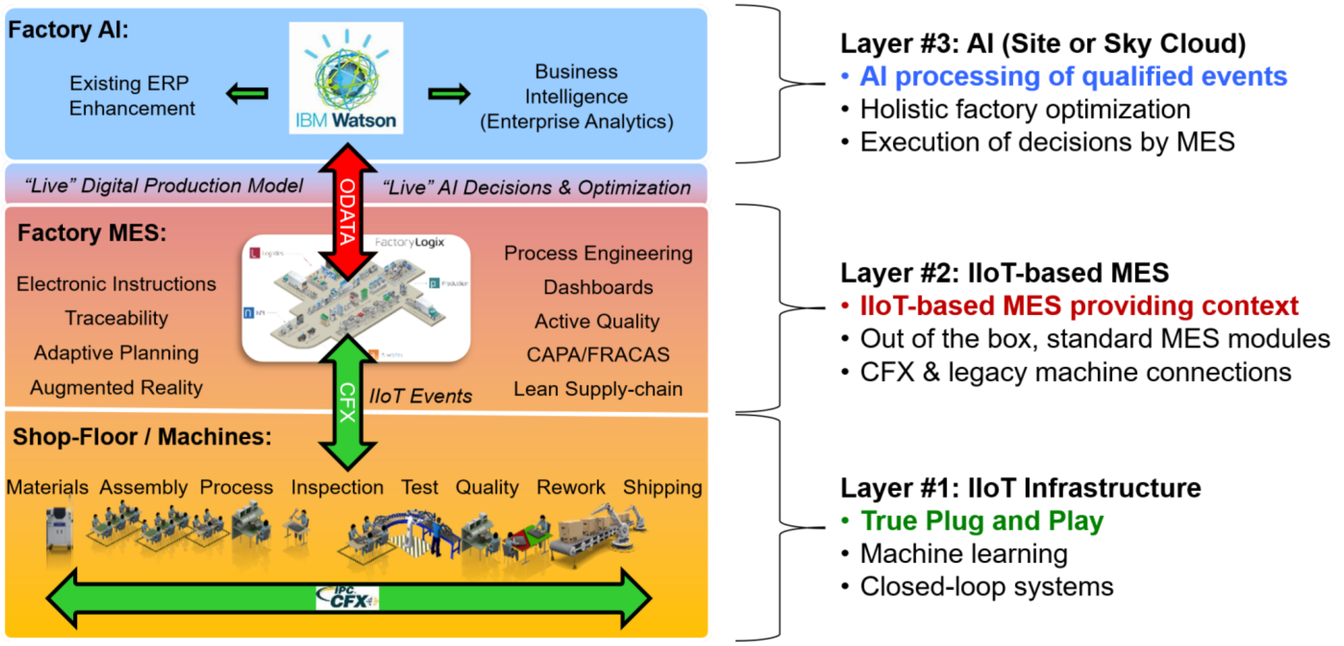

Figure 3 – The Three Layer Smart Factory Model

- **Layer #1: Shop-floor / Machines:** “Machine learning” is used to describe the specific analysis of a narrow range of data focused around a specific topic related to the machine. The results of machine learning are utilized to improve the operation manually or automatically, and can be reported to other systems. An example is the analysis of a 3D x-ray image, where deviations are detected that indicate a potential for a defect. The algorithm learns based on the results from past performance. Closed-loops are a wider application of machine learning, involving exchange of data between two or more machines, where one machine records and feeds back data related to the performance of a preceding machine. Deviations can be tracked using techniques such as 6-sigma, such that defects are avoided. CFX supports sophisticated machine to machine communication for closed-loop analysis and related machine learning algorithms.
- **Layer #2: The IIoT-based MES:** CFX IIoT data content is factual, and does not include pre-defined calculations based on assumptions. Users of CFX data at the MES layer are responsible for building contextual value, in many different ways, depending on the various MES applications. The modern IIoT-based MES uses CFX data as well as legacy interfaces to provide all of the expected MES / MOM functions, including digital manufacturing engineering with paperless documentation and Augmented Reality (AR), live execution management, near-term adaptive planning, Just In Time (JIT) material logistics and warehouse control, quality management including integrated CAPA / FRACAS capabilities, as well as fully exact compliance, conformance and traceability of all materials and process data. Since CFX messages are omni-directional, the IIoT-driven MES system also provides interaction and information from the factory layer to individual production machines and other stations, such that interoperable solutions from any vendor can perform further self-optimization based on, for example, the specific mix of products to come, or changes in the size, shape or supply-form of materials. CFX is made robust through the ability of every endpoint in the network to be capable of adding value. The IIoT-based MES layer supports the inclusion of human operators through the adoption of AR, directing the execution of complex step-by-step operations, enabling operators to be dynamically assigned to a wide range of tasks, across many different areas of the factory.
- **Layer #3: AI:** Manufacturing information provides greatest value when used both in the live environment and for post-production analysis. The use of today’s mainstream analytics software, based on the intelligent select, sort and filtering of data, when driven by contextualized data, discovers patterns that reveal opportunities for improvement. Areas of loss, waste and upcoming risk are identified, so as to recognize optimization opportunities. A wide variety of Business Intelligence and other analytics systems exist today, for which the IIoT-based MES can seamlessly provide contextualized data.

  Going beyond today’s relatively simple analytics packages, true AI is differentiated from other software algorithms in its ability to progressively modify the analysis algorithm itself to gain better results, rather than just the original parameters initially provided. Intelligent software applications, such as IBM’s Watson, gets to a layer beyond simple data selection, sort and filter-based analytics, a layer which can find solutions and opportunities that actively augment the real-time operation of the factory. The manufacturing AI of the future will make suggestions for operational improvements in real-time, which are executed by the IIoT-based MES layer. These kinds of applications will be seen in the next few years, and those who are ready with qualified and contextualized data as part of their Smart factory operations, will have the opportunity to strongly differentiate themselves, through the application of AI at the core of manufacturing management.

Value-Driven Case Studies:

Since the release of the CFX standard one year ago, many machine vendors are now getting to the completion of their support for CFX, and are making their data available to the IIoT-based MES layer. All related projects that are ongoing are governed by non-disclosure agreements, as manufacturers do not want to reveal what they are doing, at least until there is a conclusion, and even then, they only will do so if it is to their advantage. What can be talked about openly however, is the general approach that these projects are taking. Two such areas are as follows.

Case Study - Zero Defect Process Quality:

The use of process traceability data, one that is fully detailed and available, has value that goes far beyond providing scope of containment of a potential serious market issue.

Business Objectives:

The concept of zero-defects has been around for many years, though has been an elusive target for the vast majority of operations. Any risk of a defective product entering the market carries potential significant consequences. Electronics-based systems are relied upon in many safety critical applications today, such that failure is not tolerated. A zero-defect production environment would remove risk of unexpected failure. No defects should be found within the manufacturing process, as well as perfect product reliability in the market, as the occurrence of defects found early in the life of products are proportional to in-line quality levels. A single market defect in a high profile case, where for example, safety is affected, is likely to cause significant damage to the brand image, which affects sales performance of all products. Potential costs of a public product recall can negate any profits made over a significant period of time. Though such events are not planned or expected necessarily, they could happen. Meanwhile, there are costs associated with the processing of market returns through an RMA / MRO mechanism. The costs of poor quality also includes testing and inspection requirements within manufacturing, where each instance represents non added-value processing cost. If the achievement of zero-defects were to be made, then there would not be a need to perform so much testing. Perhaps the test and inspection could be done in a Smarter way, to reduce the cost and overheads. The business benefit of zero-defect manufacturing, combining all of these factors is extremely important.

Tools And Technologies Used:

CFX data is gathered from all points around the factory, with context created through the IIoT-based MES system. On top of the MES-based live shop-floor management, the data from key assembly, inspection and test processes is fed into an advanced analytics engine. The engine searches for groups of events where results are inter-related, which when taken together, have the potential to create a defect. These are called “Complex Anomalies” (CAs), which are then tracked using a procedure similar to 6-sigma. CAs are created automatically through the analysis of the variation in tested performance as a function of the combination of production parameters and prior measurements, or by a defect occurrence. Whereas the traditional approach with 6-sigma is focused on simple statistical results, the performance of CAs have a more complex relationship where, for example, three parameters which have a defined range of acceptability in isolation, but, together, a combination of valid readings may coalesce to create a risk of defect occurrence. The key is to identify CAs and understand how they can be mapped to defect prediction, which is the embedded value of the software.

Actions Taken:

Once a pattern has been detected in the monitoring of a CA that could result in an issue, there is an alert made to highlight the event as a known cause of a potential defect. The software highlights exactly which product unit is affected. Depending on the issue, process parameters or actions may need to be modified in order to reduce the risk of defect. Electronics CAPA / FRACAS procedures built into the IIoT-driven MES system, are utilized to ensure that any procedural or settings changes are applied going forward wherever needed. Continuous monitoring by the analytics software can trigger automated adjustment of parameters in order to avoid the potential defect without stopping production. For example the first two out of three data points for the CA are collected, the potential pattern recognized, and the third process being monitored is intercepted automatically, to adjust a parameter remotely to where the potential risk of defect can be completely avoided. In these ways, complex relationships of manufacturing data are analyzed together in real-time by a software AI that is always checking the conditions under which even one-off defects occur. Some cases found are related to simple process variation, some related to alternate or substitute materials, and some even relate back to a design feature, which can be communicated in the future using the IPC-DPMX (Digital Product Model Exchange) standard. Both short and long term corrective actions may be triggered, with monitoring preventing defects in the short-term at the expense potentially of production performance, with longer-term procedural changes applied to reoptimize future products’ manufacturing performance.

Results and Conclusions:

Applying such technology has the expectation that the defect rate declines dramatically. Though there is the potential of new combinations of variances being detected, this will happen before the issue becomes serious enough to have had a defect created. In addition to the elimination of defects, as CAs in the data are tracked, it may be determined that for those production units that have a very low risk of defect, need not be tested or inspected in certain areas. Test and inspection can therefore become adaptive to the known production performance, reducing costs and investment, whilst also increasing production rates. In-line x-ray inspection may become a more rigorous inspection of only those units that have experienced some form of significant variation in their CAs. Tracking of CAs can also be used to assess production configuration performance against design features or selected materials, so as to understand expected performance when comparing configurations and design rules used for DFM.

The financial benefits are quite significant, especially considering the avoided risk of the scope of any product recalls that may have otherwise occurred. While building the reputation for quality and reliability, the manufacturing business is able to compete in additional markets, where higher value manufacturing services can be provided that require the utmost in defect control. The result overall is a huge contribution to profitability.

Case Study - Predictive Maintenance:

In this case study, the use of contextualized CFX data is used to manage all of the many related aspects of equipment maintenance. Predictive maintenance is the mechanism by which maintenance is only planned and performed when needed, which is calculated based on the lifecycle and work executed by key components within machines, as well as measurement of aspects of the operation that may indicate a likelihood of premature failure, as indicated for example in the vibration, noise or energy consumption pattern of a motor.

Business Objectives:

The most serious effect of maintenance that was not done in time, is an equipment breakdown. The disruption caused by even a simple breakdown can result in the missed delivery of products to customers. It may be just one mechanism that fails, which prevents one machine from working, which in turn quickly brings a whole line to a stop. The product being made is delayed. The subsequent products that were to be run on the line are also delayed. The next line to which these products were to flow is starved of product, only then to become the bottleneck once the breakdown issue is resolved. Attempts to by-pass key equipment through schedule changes is complex, and introduces the risk of variation and defects.

Increasing maintenance frequency reduces the risk of breakdowns, though often this results in having too much maintenance performed, which reduces the utilization of the machines in the line, as well as consuming production maintenance operators and additional spare parts.

It is not only the manufacturer that benefits from predictive maintenance. The machine vendor will also have a far better understanding of when and where key spare parts are to be required, so as to optimize their supply-chain such that customers do not need to wait for any spare part deliveries, yet at the same time, there is no excess stock. Machine vendors can also perform analyses on the performance of the key components of their machines, so as to understand opportunities to upgrade parts depending on actual use-cases. This can even lead to the up-selling of future equipment which is more specifically designed for the intended need.

Tools And Technologies Used:

As with the zero-defects case, CFX data together with the associated contextualization provided by the IIoT-based MES system is used by specialist analytics software. Data is captured from machines in the form of work executed, to which is added a timeline of expected work in line with the production schedule and associated product data. Additional data from the machine in terms of internal sensor data is also included. The use of CFX represents the first opportunity to get non-product related machine data from the manufacturing floor in a way that is accepted from the security perspective. This creates a collective operation or service in which machine vendors can participate. The analytics software understands the structure and usage patterns of all of the key operational parts of the machines, and their associated lifecycle expectations. It also has the definition of the meaning of measurements from sensors that may indicate premature wearing. It then creates both a short and long-term time-based map of the maintenance jobs to be undertaken, as well as the spare parts that should be needed.

Actions Taken:

In manufacturing, the requirements for maintenance jobs is integrated into the production schedule by the MES system, with the priority for them to take place during convenient natural down-times in production. For the machine vendor, the expected requirements of spare parts, triggers Just In Time logistics. The needs of many machines, lines and even customers, can be aggregated in order to save logistics and storage costs. There is the additional analysis of equipment performance in order to understand over-stressed components which could be upgraded, as well as under-utilized machine features.

Results and Conclusions:

Applying preventative maintenance Just In Time, using the accurate prediction of the life of key operational machine parts, means that the risk of breakdown is quickly reduced to almost zero, greatly enhancing machine and line reliability. Any effort needed to schedule normal maintenance work is more than offset by the eliminated need to reschedule production following a breakdown. Most maintenance jobs are scheduled to take place at natural points of machine down-time, even if they are pulled forward or pushed backwards to an allowable extent depending on the relative risk assessment versus production opportunity cost. There is a reduction in the engineering effort used for maintenance, including stresses associated with a breakdown condition.

From a business standpoint, the risk of missed deliveries is greatly reduced, the utilization of machines and lines increased, together with a reduction in the cost of maintenance overall. For the machine vendor, there are significant cost savings in terms of spare parts, in addition to which is the identification of more cost-effective options for spare parts, as a feed-back to the design of the parts themselves. There is also opportunity for increased sales of more specified equipment or tool options, as well as the avoidance of issues where non OEM parts have been used.

Summary – Smart Factory Best Practices:

These two case studies are amongst many applications that may not be new as ideas in themselves, but are now completely viable with the creation of the CFX IIoT technology, the use of an IIoT-based MES solution and the creation of AI-based analytic systems. It is essential that throughout the journey to the Cognitive Smart Enterprise, that decisions are made as to which technologies and solutions to adopt, step by step, that result in immediate benefit, but also contribute as an overall step toward the ultimate Smart factory goals, such that no opportunity is excluded along the way. These case studies, along with many others for which discussion in the industry has started, show that there are rapidly increasing benefits to be obtained from data the further towards the goal of level 5 cognitive factory you are. Journeys with other technologies can lead to very high unnecessary costs, that do yield value temporarily, but which ultimately lead to escalating costs in a scenario where additional benefits cannot be achieved. It is essential that decisions around the adoption of Smart factory technologies are understood in terms of both short-term gain, and future interoperability with additional functions and solutions.